

JCT 625  
66/87/50  
U.S. PTO

# UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications  
under 37 CFR 1.53(b))

Attorney Docket No. 990527 Total Pages

U.S. PTO  
JC625  
00000000000000000000000000000000  
06/18/09

First Named Inventor or Application Identifier

Akito KURAMATA, Shinichi KUBOTA,  
Kazuhiko HORINO and Reiko SOEJIMA

Check Box, if applicable [ ] Duplicate

Express Mail Label No.

APPLICATION ELEMENTS FOR:  
**OPTICAL SEMICONDUCTOR DEVICE HAVING AN  
EPITAXIAL LAYER OF III-V COMPOUND  
SEMICONDUCTOR MATERIAL CONTAINING N AS A  
GROUP V ELEMENT**

ADDRESS TO: Assistant Commissioner for Patents  
BOX PATENT APPLICATIONS  
Washington, D.C. 20231

1. [XX] Fee Transmittal Form (Incorporated within this form) (The filing fee is deferred).
2. [XX] Specification Total Pages [59]
3. [XX] Drawing(s) (35 USC 113) Total Sheets [20]
4. [ ] Oath or Declaration Total Pages [ ]  
Not attached; deferred under P. L. 97-247.
  - a. [ ] Newly executed (original or copy)
  - b. [ ] Copy from prior application (37 CFR 1.63(d))  
(for continuation/divisional with Box 17 completed).
    - i. [ ] Deletion of Inventor(s)  
Signed statement attached deleting inventor(s) named in prior application,  
see 37 CFR 1.63(d)(2) and 1.33(b).
5. [ ] Incorporation by reference (useable if box 4b is checked)  
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.
6. [ ] Microfiche Computer Program (Appendix)
7. [ ] Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
  - a. [ ] Computer Readable Copy
  - b. [ ] Paper Copy (identical to computer copy)
  - c. [ ] Statement Verifying identity of above copies
8. [ ] Assignment Papers (cover sheet and document(s))
9. [ ] 37 CFR 3.73(b) Statement (when there is an assignee) [ ] Power of Attorney

## ACCOMPANYING APPLICATION PARTS

8. [ ] Assignment Papers (cover sheet and document(s))
9. [ ] 37 CFR 3.73(b) Statement (when there is an assignee) [ ] Power of Attorney

**UTILITY PATENT  
APPLICATION TRANSMITTAL**  
(Only for new nonprovisional applications  
under 37 CFR 1.53(b))

Attorney Docket No.	<b>990527</b>
First Named Inventor or Application Identifier	
<b>Akito KURAMATA, Shinichi KUBOTA, Kazuhiko HORINO and Reiko SOEJIMA</b>	
<b>PAGE 2 OF 3</b>	

10.  English translation Document (if applicable)
11.  Information Disclosure Statement       Copies of IDS Citations
12.  Preliminary Amendment
13.  Return Receipt Postcard (MPEP 503)
14.  Small Entity Statement(s)       Statement filed in prior application  
Status still proper and desired.
15.  Claim for Convention Priority       Certified copy of Priority Document(s)  
  
a. Priority of \_\_\_\_\_ application no. \_\_\_\_\_ filed on \_\_\_\_\_ is claimed under 35 USC 119.  
The certified copies/copy have/has been filed in prior application Serial No. \_\_\_\_\_.  
(For Continuing Applications, if applicable).
16.  Other \_\_\_\_\_
17. If a CONTINUING APPLICATION, check appropriate box and supply the requisite information:  
 Continuation  Division  Continuation-in-part (CIP) of prior application no. \_\_\_\_/\_\_\_\_

FEE TRANSMITTAL	Number Filed	Number Extra	Rate	Basic Fee \$760.00
<b>The filing fee is calculated below</b>				
Total Claims	24 - 20	4	x \$18.00	72.00
Independent Claims	8 - 3	5	x \$78.00	390.00
Multiple Dependent Claims			\$260.00	
			<b>Basic Filing Fee</b>	<b>1222.00</b>
Reduction by 1/2 for small entity				
Fee for recording enclosed Assignment			\$40.00	40.00
<b>TOTAL</b>				<b>1262.00</b>

**XX NO FEE ENCLOSED. THE FILING FEE IS DEFERRED.**

**UTILITY PATENT  
APPLICATION TRANSMITTAL**  
(Only for new nonprovisional applications  
under 37 CFR 1.53(b))

Attorney Docket No.	990527
First Named Inventor or Application Identifier	
Akito KURAMATA, Shinichi KUBOTA, Kazuhiko HORINO and Reiko SOEJIMA	
PAGE 3 OF 3	

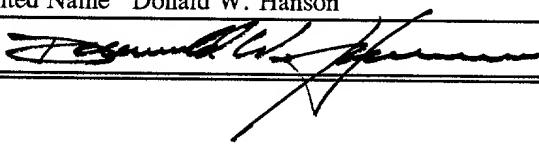
- A check in the amount of \_\_\_\_\_ is enclosed to cover the filing fee of \_\_\_\_\_ and the assignment recordation fee of \_\_\_\_\_.
- Please charge our Deposit Account No. **01-2340** in the total amount of \_\_\_\_\_ to cover the filing fee and the \_\_\_\_\_ assignment recordation fee. A duplicate of this sheet is attached.
- The Commissioner is hereby authorized to charge payment for any additional filing fees required under 37 CFR 1.16 or credit any overpayment to Deposit Account No. **01-2340**.

**8. CORRESPONDENCE ADDRESS**

ARMSTRONG, WESTERMAN, HATTORI  
McLELAND & NAUGHTON  
1725 K Street, N.W. Suite 1000  
Washington, D.C. 20006  
Telephone: (202) 659-2930  
Facsimile: (202) 887-0357

**SUBMITTED BY**

Typed or Printed Name Donald W. Hanson      Reg. No. 27,133

Signature  Date: May 18, 1999

DWH/yap

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, Akito Kuramata, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Shinichi Kubota, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Kazuhiko Horino, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan and Reiko Soejima, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan have invented certain new and useful improvements in

OPTICAL SEMICONDUCTOR DEVICE HAVING AN EPITAXIAL  
LAYER OF III-V COMPOUND SEMICONDUCTOR MATERIAL  
CONTAINING N AS A GROUP V ELEMENT

of which the following is a specification : -

1      TITLE OF THE INVENTION

OPTICAL SEMICONDUCTOR DEVICE HAVING AN  
EPITAXIAL LAYER OF III-V COMPOUND SEMICONDUCTOR  
MATERIAL CONTAINING N AS A GROUP V ELEMENT

5

BACKGROUND OF THE INVENTION

The present invention generally relates to optical semiconductor devices and more particularly to a GaN-family laser diode producing blue to ultraviolet radiation and a fabrication process thereof.

Laser diodes, light-emitting diodes and photodiodes are optical semiconductor devices used extensively in the field of optical telecommunication, optical information processing, recording of information, and the like.

In the case of laser diode, there is a demand, particularly in the field of optical information recording, for a laser diode operable in the optical wavelength band of blue to ultraviolet radiation for increasing the recording density. It should be noted a laser diode oscillates generally in the optical wavelength band of red to infrared radiation. Further, there is a demand for a photodiode operable in such a short optical wavelength band.

Conventionally, GaN, having a large bandgap, has been recognized as a promising material for constructing an optical semiconductor device such as a laser diode or photodiode that operates in the foregoing blue to ultraviolet wavelength band. A light-emitting diode using a GaN crystal for the active layer thereof is already put into practical use. Further, a laser diode having a double heterostructure of GaN/InGaN/GaN is already known. By incorporating an appropriate impurity element into the GaN crystal, it is also possible to cause the laser diode to oscillate in the visible wavelength band of

1 green radiation.

It should be noted that GaN has a Wurtzite structure belonging to the hexagonal crystal system, and the preparation of a single crystal substrate of 5 GaN is difficult. Thus, the optical semiconductor devices that use GaN for the active layer have been constructed on the c-surface of a sapphire ( $\text{Al}_2\text{O}_3$ ) substrate, which also belongs to the hexagonal crystal system. Thereby, the GaN active layer is grown on the 10 foregoing c-surface of sapphire substrate epitaxially.

FIG.1 shows the construction of a conventional GaN-family laser diode 1 operable in the optical wavelength band of blue to ultraviolet 15 radiation.

Referring to FIG.1, the laser diode 1 is formed on a sapphire substrate 11 and includes a GaN buffer layer 12 formed on the substrate 11, an n-type GaN electrode layer 13 formed on the GaN buffer layer 12, and a lower cladding layer 14 of n-type AlGaN 20 formed on the electrode layer with a composition of  $\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$ .

On the lower cladding layer 14, there is formed an optical waveguide layer 15 of n-type GaN, and an active layer having a multiple quantum well 25 (MQW) structure is formed on the n-type optical waveguide layer 15 epitaxially, wherein the MQW structure includes a repetitive stacking of a unit structure of undoped InGaN quantum well layer sandwiched by a pair of undoped GaN barrier layers.

The active layer 15 is covered by an optical waveguide layer 17 of p-type GaN, and an upper cladding layer 18 of p-type AlGaN is formed on the optical waveguide layer 17 with a composition of  $\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$ . The upper cladding layer 18 is formed 30 with an optical waveguide ridge 18A extending in the axial direction of the laser diode at a laterally 35 central part thereof, and a contact layer 19 of p-type

1      GaN is formed on the top surface of the optical  
waveguide ridge 18A.

5      The upper cladding layer 18 and the GaN  
contact layer 19, including both side walls of the  
optical waveguide ridge 18A, are covered by an  
insulation film 20 of SiO<sub>2</sub>, and a p-side electrode 21  
is formed on the insulation film 20 in electrical  
contact with the GaN contact layer at the optical  
waveguide ridge 18A via a via-hole formed in the  
10     insulation film 20.

15     The foregoing semiconductor layers 14 - 18  
form together a stacked layered structure defined by  
two vertical side walls W<sub>1</sub> and W<sub>2</sub> extending  
substantially vertically to the principal surface of  
the substrate 11. Further, there is formed an optical  
cavity in the stacked layered structure by a pair of  
mirror surfaces disposed so as to face in a direction  
perpendicularly to the sheet of FIG.1.

20     Further, the substrate 11, buffer layer 12  
and the electrode layer 13 thereon extend laterally  
beyond the foregoing side wall surface W<sub>2</sub>, and an n-  
side electrode 22 is provided on the electrode layer  
13. The laser diode of FIG.1 oscillates in the  
optical wavelength of 390 - 420 nm and has an  
25     important application in the field of high-density  
information recording.

30     The laser diode of FIG.1, however, has a  
drawback in that, due to the existence of large  
lattice misfit of as much as 13% or more at the  
heteroepitaxial interface between the c-surface of the  
35     sapphire single crystal substrate 11 and the GaN  
epitaxial layer 12, the epitaxial layers 15 - 17  
forming the MQW structure 16 tend to include various  
crystal defects with a high concentration level.  
Further, the laser diode 1 of FIG.1 has a difficulty,  
contrary to the conventional edge-emission type, in  
that formation of the electrode on the bottom surface

1 of the sapphire substrate 11 is difficult. Thereby,  
the construction, and hence the fabrication process of  
the laser diode becomes inevitably complex. In  
addition, the sapphire substrate used in the laser  
5 diode 1 is difficult to be cleaved, and thus, it is  
difficult in the laser diode 1 to form the mirror  
surfaces by a conventional cleaving process, contrary  
to the conventional edge-emission type laser diode  
constructed on a substrate having a zinc blende  
10 structure.

In the laser diode 1 of FIG.1, the foregoing  
mirror surfaces are formed by a dry etching process,  
while such a process of forming the mirror surface by  
a dry etching process takes a substantial time.  
15 Further, the quality of the mirror surfaces thus  
formed is inferior, in terms of flatness and angle, to  
the quality of the mirror surfaces formed by a  
cleaving process.

It is also proposed to use a conductive SiC  
20 substrate, which also belongs to the hexagonal crystal  
system, in place of the sapphire substrate and form  
the GaN-family active layer of the optical  
semiconductor on such an SiC substrate. For example,  
the Japanese Laid-Open Patent Publication 10-135576  
25 describes a technology of growing a GaN-family active  
layer on the (0001)Si surface of a 6H-SiC single  
crystal substrate epitaxially. It should be note that  
use of an SiC substrate has various advantageous  
features such as small lattice misfit, less than 4%,  
30 between the GaN active layer and the SiC substrate,  
electrical conductivity of the substrate, and  
excellent thermal conductivity of the substrate, which  
is superior to that of a sapphire substrate. Thus, by  
using an SiC substrate, it is possible to construct a  
35 laser diode oscillating in the optical wavelength of  
blue to violet radiation by using a construction  
similar to that of a conventional edge-emission type

1      laser diode.

In order to construct an optical semiconductor device that uses a GaN-family active layer formed on such an SiC substrate epitaxially, it  
5      is necessary to establish a technology to form a GaN buffer layer on the SiC substrate epitaxially.  
Unfortunately, it is known that an epitaxial growth of a GaN layer tends to lead to an island-like growth when the growth is conducted on a SiC substrate. When  
10     such an island-like growth occurs in the buffer layer, it is difficult to form the GaN-family active layer thereon with a planarized top surface. Further, the GaN-family active layer thus formed tends to incorporate therein various crystal defects, while  
15     such crystal defects impedes the interaction occurring in the active layer between GaN and photons. Thereby, the efficiency of laser oscillation is deteriorated seriously.

It is known that the problem of island-like  
20     growth of GaN film is avoided when the SiC substrate is covered by a buffer layer of AlN or AlGaN, such that the desired epitaxial growth of the GaN active layer occurs on such a buffer layer. However, it has been not possible to provide electrical conductivity  
25     to an AlN film used for the buffer layer.

When a buffer layer of AlGaN is used, on the other hand, it is possible to provide an n-type conductivity to the buffer layer, as long as the content of Al in the AlGaN buffer layer does not  
30     exceed 40%. Thus, as long as the composition of the AlGaN layer is controlled as such, it is possible to electrically interconnect the GaN active layer with the SiC substrate via the AlGaN buffer layer.

On the other hand, the condition of forming  
35     the conductive AlGaN epitaxial film on a SiC substrate with a flat and smooth top surface suitable for forming an active layer of GaN thereon, has not been

1 explored to the date.

SUMMARY OF THE INVENTION

5 Accordingly, it is an object of the present invention to provide a novel and useful optical semiconductor device and a fabrication process thereof wherein the foregoing problems are successfully eliminated.

10 Another and more specific object of the present invention is to provide an optical semiconductor device having an SiC substrate and a nitride layer of a group III element including Ga formed epitaxially on the substrate, wherein the epitaxial layer has a flat and smooth top surface and  
15 that an excellent electrical interconnection is secured between the SiC substrate and the nitride epitaxial layer.

20 Another object of the present invention is to provide an optical semiconductor device having a simple structure for confining the electric currents injected to the laser diode into a desired stripe region and is simultaneously capable of controlling the transverse mode oscillation in the state that laser diode produces a high-power optical output.

25 Another object of the present invention is to provide an optical semiconductor device having a selectively grown region of nitride and a fabrication process thereof.

30 Another object of the present invention is to provide an optical semiconductor device having a nitride active layer of a group III element including Ga and an electron blocking layer provided for preventing overflowing of electrons from the active layer, wherein the doping of the electron blocking  
35 layer is optimized such that crack formation is minimized, the carrier confinement in the active layer is maximized and the threshold voltage of laser

1 oscillation is minimized.

Another object of the present invention is  
to provide an optical semiconductor device,  
comprising:

5 a substrate of SiC having a first  
conductivity type;

a buffer layer of AlGaN formed on said  
substrate epitaxially, said buffer layer having said  
first conductivity type and a composition represented  
10 as  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ;

a first cladding layer having said first  
conductivity type, said first cladding layer being  
formed on said buffer layer epitaxially;

15 an active layer formed epitaxially on said  
first cladding layer;

a second cladding layer having a second,  
opposite conductivity type, said second cladding layer  
being formed on said active layer epitaxially;

20 a first electrode provided so as to inject  
first-type carriers having a first polarity into said  
second cladding layer; and

a second electrode provided on said  
substrate so as to inject second-type carriers having  
a second polarity,

25 said buffer layer containing said first type  
carriers with a concentration level from  $3 \times 10^{18} \text{ cm}^{-3}$   
to  $1 \times 10^{20} \text{ cm}^{-3}$  and said compositional parameter x  
larger than 0 but smaller than 0.4 ( $0 < x < 0.4$ ).

According to the present invention, the  
30 resistance at the interface between the substrate and  
the buffer layer is effectively minimized.

Another object of the present invention is  
to provide an optical semiconductor device,  
comprising:

35 a substrate of SiC having a first  
conductivity type;

a buffer layer of AlGaN formed on said

- 1        substrate epitaxially;
- 2              a first cladding layer of AlGaN having said first conductivity type, said first cladding layer being formed on said buffer layer epitaxially;
- 3        an optical waveguide layer of GaN having said first conductivity type, said optical waveguide layer being formed on said first cladding layer epitaxially;
- 4              an active layer formed epitaxially on said optical waveguide layer, said active layer containing Ga as a group III element and N as a group V element;
- 5              a second cladding layer of AlGaN having a second, opposite conductivity type, said second cladding layer being formed on said active layer epitaxially;
- 6              a first electrode provided so as to inject first-type carriers having a first polarity into said second cladding layer; and
- 7        a second electrode provided on said substrate so as to inject second-type carriers having a second polarity,
- 8              said substrate having a top surface separated from a bottom surface of said active layer by a distance of about 1.6 μm or more.
- 9        According to the present invention, the threshold current of the optical semiconductor device is successfully minimized.
- 10          Another object of the present invention is to provide an optical semiconductor device, comprising:
- 11              a substrate of SiC having a first conductivity type;
- 12              a first cladding layer having a first conductivity type, said first cladding layer being formed on said substrate epitaxially;
- 13              an active layer formed epitaxially on said first cladding layer;

- 1        a second cladding layer having a second,  
opposite conductivity type, said second cladding layer  
being formed on said active layer epitaxially;
- 5        a third cladding layer having said second  
conductivity type, said third cladding layer being  
formed on said second cladding layer epitaxially;
- 10      a first electrode provided so as to inject  
first-type carriers having a first polarity into said  
second cladding layer; and
- 15      a second electrode provided on said  
substrate so as to inject second-type carriers having  
a second polarity,  
      said third cladding layer having a ridge  
structure,
- 20      wherein an insulating film is interposed  
between said second cladding layer and said third  
cladding layer, said insulating film having an opening  
in correspondence to said ridge structure, with a  
width smaller than a width of said ridge structure.
- 25      According to the present invention, the  
injection of the drive current is made into an  
narrowly confined region of the ridge structure, and  
an efficient control is made on the laser oscillation  
of the horizontal transverse mode. As a result, the  
optical semiconductor device shows a smooth  
operational characteristic free from kink from a low-  
power state producing a low-power optical beam to a  
high-power state producing a high-power optical beam.
- 30      Another object of the present invention is  
to provide an optical semiconductor device,  
comprising:
- 35      a substrate of SiC having a first  
conductivity type;
- a first cladding layer having a first  
conductivity type, said first cladding layer being  
formed on said substrate epitaxially;
- an active layer formed epitaxially on said

1        first cladding layer;  
            a second cladding layer having a second,  
opposite conductivity type, said second cladding layer  
being formed on said active layer epitaxially;  
5        a third cladding layer having said second  
conductivity type, said third cladding layer being  
formed on said second cladding layer epitaxially;  
            a contact layer of said second conductivity  
type, said contact layer being formed on said third  
10      cladding layer;  
            a first electrode provided on said contact  
layer;  
            a second electrode provided on said  
substrate;  
15      said third cladding layer forming a ridge  
structure having a T-shaped cross-section,  
            said third cladding layer including, at a  
bottom part thereof, a pair of cuts, such that said  
cuts penetrate from respective lateral sides of said  
20      ridge structure toward a center of said ridge  
structure.

According to the present invention, the area  
of the insulation mask used in corresponding to the  
foregoing cuts when forming the third cladding layer  
25      by a selective growth process is effectively  
minimized, and the formation of particles on the  
insulation film is minimized accordingly. As the  
insulation mask itself is removed after the selective  
growth process and before the step of forming the  
30      first electrode, the problem of deterioration of  
adhesion caused in the first electrode as a result of  
the existence of the particles is successfully  
eliminated. As the third cladding layer thus formed  
has a T-shaped cross-section characterized by a  
35      narrowly confined bottom part, the optical  
semiconductor device of the present invention is  
capable of injecting drive current selectively into

1 the ridge region.

Another object of the present invention is to provide a method of fabricating an optical semiconductor device, comprising the steps of:

5 forming an insulation pattern on a semiconductor layer such that said insulation pattern has an opening; and

10 forming, on said insulation pattern, a regrowth region of a nitride of Al and a group III element in correspondence to said opening,

15 said step of forming the regrowth region being conducted by an metal-organic vapor phase epitaxy process.

According to the present invention, it becomes possible to form a regrowth region of a nitride of Al and a group III element on the insulation mask in correspondence to the opening formed in the mask by using an MOVPE (metal-organic vapor phase epitaxy) process. By using halogen together with the gaseous source in the MOVPE process, the formation of particles on the insulation mask is minimized.

20 Another object of the present invention is to provide an optical semiconductor device, comprising:

25 a substrate;  
a first cladding layer of a nitride of a group III element formed epitaxially on said substrate, said first cladding layer having an n-type conductivity;

30 a first optical waveguide layer of a nitride of a group III element formed epitaxially on said first cladding layer, said first optical waveguide layer having an n-type conductivity;

35 an active layer of a nitride of a group III element formed epitaxially on said first optical waveguide layer;

- 1       an electron blocking layer of a nitride of a group III element formed epitaxially on said active layer, said electron blocking layer having a p-type conductivity;
- 5       a second optical waveguide layer of a nitride of a group III element formed epitaxially on said electron blocking layer, said second optical waveguide layer having a p-type conductivity;
- 10      a second cladding layer of a nitride of a group III element formed epitaxially on said second optical waveguide layer, said second cladding layer having a p-type conductivity;
- 15      a contact layer of a nitride of a group III element formed epitaxially on said second cladding layer, said contact layer having a p-type conductivity;
- 20      a first electrode provided on said contact layer; and
- 25      a second electrode provided on said substrate;  
each of said electron blocking layer, said second optical waveguide layer and said second cladding layer being doped by Mg;  
wherein said second optical waveguide layer and said second cladding layer contain Mg therein with a concentration level lower than a concentration level of Mg in any of said electron blocking layer and said contact layer.
- 30      According to the present invention, the problem of cracking of the epitaxial layers in the optical semiconductor device is minimized. Further, the drive voltage of the optical semiconductor device is also minimized.
- 35      Another object of the present invention is to provide a semiconductor wafer, comprising:  
an SiC substrate having an n-type conductivity; and

1       an AlGaN layer having an n-type conductivity  
formed on said SiC substrate with a composition  
represented as  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ,

5       wherein said AlGaN layer has a carrier  
density in the range between  $3 \times 10^{18} - 1 \times 10^{20} \text{ cm}^{-3}$ ,  
and

      wherein said compositional parameter x is  
larger than 0 but smaller than 0.4 ( $0 < x < 0.4$ ).

10      According to the present invention, the  
resistance at the interface between the SiC substrate  
and the AlGaN buffer layer is minimized.

15      Other objects and further features of the  
present invention will become apparent from the  
following detailed description when read in  
conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG.1 is a diagram showing the construction  
of a conventional GaN-family laser diode;

20      FIGS.2A and 2B are diagrams showing the  
experiments constituting one of the basis of the  
present invention;

25      FIG.3 is another diagram showing the  
experiments constituting one of the basis of the  
present invention;

FIG.4 is another diagram showing the  
experiments constituting one of the basis of the  
present invention;

30      FIG.5 is another diagram showing the  
experiments constituting one of the basis of the  
present invention;

35      FIGS.6A and 6B are diagrams showing the  
construction of a laser diode according to a first  
embodiment of the present invention;

FIG.7 is a diagram showing the experiments  
constituting one of the basis of the present

1 invention;

FIG.8 is a diagram showing the construction  
of a laser diode according to a second embodiment of  
the present invention;

5 FIG.9 is a diagram showing a modification of  
the laser diode of FIG.8;

FIGS.10A and 10B are diagrams showing the  
fabrication process of a laser diode according to a  
third embodiment of the present invention;

10 FIG.11 is a diagram showing a modification  
of the laser diode of the third embodiment;

FIGS.12A and 12B are diagrams showing the  
construction of a mask used in a selective growth  
process when fabricating the laser diode of the third  
15 embodiment and a laser diode of a fourth embodiment of  
the present invention;

FIG.13 is a diagram showing the construction  
of a laser diode according to the fourth embodiment of  
the present invention;

20 FIGS.14A - 14F are diagrams showing the  
fabrication process of a laser diode according to a  
fifth embodiment of the present invention;

FIG.15 is a diagram showing a distribution  
of Mg in a conventional laser diode;

25 FIG.16 is a diagram showing the experiments  
constituting one of the basis of the present  
invention;

FIG.17 is a diagram showing the experiments  
constituting one of the basis of the present  
30 invention;

FIG.18 is a diagram showing a Mg  
distribution used in a laser diode according to a  
sixth embodiment of the present invention;

35 FIG.19 is a diagram showing a Mg  
distribution according to a modification of the sixth  
embodiment.

1      DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[FIRST EMBODIMENT]

In the description hereinafter, the mixed crystal having the composition  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  ( $0 < x < 0.4$ ) will be designated merely as AlGaN. When the AlGaN mixed crystal has a composition falling in the foregoing range ( $0 < x < 0.4$ ), the doping of AlGaN is possible. Further, the AlGaN mixed crystal having such a composition can be grown on an SiC substrate with a flat and smooth top surface. The epitaxial growth of the AlGaN mixed crystal is typically conducted by an MOVPE process, wherein the epitaxial layer thus formed shows a flat and smooth top surface when the deposition is made under a pressure of 100 Torr and the AlGaN mixed crystal contains Al with an atomic fraction  $x$  of 0.09 or more.

Thus, it is possible to construct a GaN-family laser diode on an n-type SiC substrate covered by an n-type  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  buffer layer, by depositing desired epitaxial layers of GaN or a mixed crystal of GaN. The laser diode thus formed typically oscillates at the wavelength of 420 nm and has a threshold current of about 500 mA. While the laser diode thus formed oscillates at the desired blue to ultraviolet wavelength band as is expected, the laser diode also has a drawback in that the threshold voltage necessary for laser oscillation is very large, as large as about 22V. In view of the built-in potential of about 3V for the pn junction in a GaN crystal, the threshold voltage of the laser diode should be about 4 - 5 V if the laser diode is fabricated properly. Thus, the foregoing threshold voltage of 22V is deemed excessively large for a GaN-family laser diode.

The inventor of the present invention has conducted a series of experiments on the AlGaN/SiC epitaxial system in the investigation forming the basis of the present invention, and discovered that

I the foregoing large threshold voltage arises as a result of large AlGaN/SiC interface resistance between the SiC substrate and the AlGaN buffer layer.

In view of the fact that the band structure of SiC and AlGaN is not yet established to the date, and further in view of the expected existence of concentration of crystal defects at the interface between the SiC substrate and the AlGaN buffer layer, the theoretical approach for reducing the AlGaN/SiC interface resistance is expected to be difficult.

Thus, the present invention explored the solution for reducing the AlGaN/SiC interface resistance experimentally.

FIG.2A shows the construction of the sample used in the experiment.

Referring to FIG.2A, a bulk crystal ingot of Wurtzite-type 6H-SiC, doped by N to the n-type and grown by an improved Rayleigh process, was used for forming an SiC substrate 1. More specifically, the SiC substrate 1 was formed from the foregoing 6H-SiC bulk crystal ingot to have a thickness of about 200  $\mu\text{m}$ , wherein the substrate 1 thus formed was defined by a principal surface of (0001)Si having a surface area of about 1  $\text{cm}^2$ . The foregoing (0001)Si principal surface of the substrate 1 was then covered by a buffer layer 2 of n-type AlGaN grown thereon epitaxially by an MOVPE process with a thickness of about 1  $\mu\text{m}$ . The AlGaN buffer layer 2 thus formed was doped by Si to the n-type. The MOVPE process for forming the buffer layer 2 was conducted at the substrate temperature of 1090°C while using the gaseous sources of TMG (trimethylgallium), TEG (triethylgallium), TMA (trimethylaluminum) and ammonia ( $\text{NH}_3$ ) together with an impurity gaseous source of monosilane ( $\text{SiH}_4$ ).

After the formation of the buffer layer 2, a contact layer 3 of n-type GaN was grown further on the

1 buffer layer 2 by an MOVPE process with a thickness of  
about 0.2  $\mu\text{m}$  for reducing the contact resistance.

5 After the formation of the contact layer 3,  
a circular or stripe-shaped electrode 6 was formed on  
the GeN contact layer for measurement of the AlGaN/SiC  
interface resistance, more specifically the  
resistivity, between the substrate 1 and the buffer  
layer 2, and a Ni electrode 5 was provided on the  
bottom principal surface of the substrate 1 so as to  
10 cover the entirety thereof. It should be noted that  
the electrode 6 has a stacked structure including a  
lower layer of Ti and an upper layer of Al, wherein  
the electrode 6 was formed to have a diameter of 30 -  
90  $\mu\text{m}$  when the electrode 6 has a circular shape. When  
15 the electrode 6 has a stripe structure, the electrode  
6 was formed of a stripe having a width of 2 - 15  $\mu\text{m}$   
and a length of 300 - 900  $\mu\text{m}$ .

20 In the experiment, the carrier density was  
changed variously in the n-type AlGaN buffer layer 2  
and also in the n-type SiC substrate, in combination  
with the Al content in the buffer layer 2 and the  
pressure used in the MOVPE process.

25 FIG.2B shows the interface resistivity at  
the interface between the n-type SiC substrate 1 and  
the n-type AlGaN buffer layer 2 for the case the  
carrier density was changed, wherein the horizontal  
axis of FIG.2B represents the n-type carrier density  
30 ( $\text{cm}^{-3}$ ) in the AlGaN buffer layer 2 in a logarithmic  
scale, while the vertical axis of FIG.2B represents  
the AlGaN/SiC interface resistivity ( $\Omega\text{cm}^2$ ) also in a  
logarithmic scale. In the experiment of FIG.2B, the  
carrier density in the SiC substrate 1 was set to  $1 \times$   
 $10^{17}\text{cm}^{-3}$  and the Al content x of the AlGaN buffer  
layer 2 was set to 0.09 ( $x = 0.09$ ).

35 Referring to FIG.2B, there are represented  
the value of the AlGaN/SiC interface resistivity for  
the structure of FIG.2A in which the carrier density

1 in the n-type AlGaN buffer layer 2 is changed from  $1 \times 10^{17} \text{ cm}^{-3}$  to  $1 \times 10^{20} \text{ cm}^{-3}$ . In the construction of  
5 FIG.2A, it should be noted that the bulk resistance is negligible for the electrodes 5 and 6, the SiC substrate 1, the AlGaN buffer layer 2 and the GaN contact layer 3. Further, the contact resistance of the electrode, more specifically the interface resistance at the interface between the AlGaN buffer layer 2 and the contact layer 3, is also negligible.  
10 Thus, the resistance measured across the electrodes 5 and 6 fairly represents the AlGaN/SiC interface resistance between the SiC substrate 1 and the AlGaN buffer layer 2.

As will be apparent from FIG.2B, the plot of  
15 the resistivity reveals the existence of two lines  $r_1$  and  $r_2$ . More specifically, the experimental points are aligned on a line  $r_2$  having a gentle gradient in the range of the carrier density larger than about  $5 \times 10^{18} \text{ cm}^{-3}$ , while the experimental points are aligned on  
20 a more steeper line  $r_1$  when the carrier density is lower than the foregoing value of about  $5 \times 10^{18} \text{ cm}^{-3}$ .

It should be noted that the gentle gradient of the line  $r_2$  indicates that the change of the AlGaN/SiC interface resistivity is small when the  
25 carrier density is changed. The existence of the two lines,  $r_1$  and  $r_2$ , suggests that the physical phenomenon occurring in the range of the line  $r_1$  may be different from the physical phenomenon occurring in the range of the line  $r_2$ . From FIG.2B, it will be  
30 understood that a low interface resistivity is realized with reliability, by setting the carrier density in the n-type AlGaN buffer layer 2 to be larger than about  $5 \times 10^{18} \text{ cm}^{-3}$ .

In a GaN-family laser diode having a mesa  
35 structure, the entire resistance of the epitaxial layers generally takes the value of about  $10\Omega$ . Thereby, it is desired and necessary that the

1 AlGaN/SiC interface resistance is substantially lower  
than the total resistance of the epitaxial layers.

5 In the event each epitaxial layer has a size  
of 700  $\mu\text{m} \times 4 \mu\text{m}$ , the AlGaN/SiC interface resistance  
can be positively reduced to be smaller than the  
resistance of the entire epitaxial layers, even when  
the carrier density in the epitaxial layers is in the  
order of  $3 \times 10^{18} \text{cm}^{-3}$ . Thus, it is preferable to dope  
10 the n-type AlGaN layer 2 to have a carrier density of  
 $3 \times 10^{18} \text{cm}^{-3}$  or more, more preferable about  $5 \times 10^{18} \text{cm}^{-3}$  or more.

In doping the n-type AlGaN buffer layer 2,  
it was discovered that there appears a large amount of  
crystal defects on the surface of the AlGaN layer 2  
15 when the carrier density in the layer 2 is set larger  
than the value of  $1 \times 10^{20} \text{cm}^{-3}$ . Due to the excessive  
formation of the crystal defects, experiment for  
measuring the interface resistivity was not possible  
in this case. Thus, it is preferable that the carrier  
20 density in the n-type AlGaN buffer layer 2 does not  
exceed the foregoing value of about  $1 \times 10^{20} \text{cm}^{-3}$ .

In the foregoing experiments, the carrier  
density of the n-type AlGaN buffer layer 2 on the n-  
type SiC substrate 1 was changed variously, while in  
25 the second-series experiments that follow the  
foregoing first-series experiments, the AlGaN/SiC  
interface resistivity was measured while changing the  
carrier density in the n-type SiC substrate 1  
variously. In the second-series experiments, the  
30 composition of the n-type AlGaN buffer layer 2 was set  
to have an Al content x of 0.09 ( $x = 0.09$ ) and the  
carrier density of  $5 \times 10^{18} \text{cm}^{-3}$ .

FIG.3 shows the result of measurement of the  
AlGaN/SiC interface resistivity for various carrier  
35 densities in the n-type SiC substrate 1 in the range  
from  $1 \times 10^{17} \text{cm}^{-3}$  to  $3 \times 10^{19} \text{cm}^{-3}$ , wherein the  
horizontal axis shows the carrier density ( $\text{cm}^{-3}$ )

1 represented in a logarithmic scale, while the vertical  
axis represents the AlGaN/SiC interface resistivity  
( $\Omega\text{cm}$ ) in a logarithmic scale.

5 As can be seen clearly from FIG.3, the  
experimental points are aligned on two lines  $r_3$  and  
 $r_4$ . More specifically, the AlGaN/SiC interface  
resistivity is represented by the line  $r_3$  in the range  
of the carrier density smaller than about  $1 \times 10^{18}\text{cm}^{-3}$ . In the range of the carrier density larger than  
10 about  $1 \times 10^{18}\text{cm}^{-3}$ , on the other hand, the AlGaN/SiC  
interface resistivity is represented by the line  $r_4$ .

In the second-series experiments, it was  
discovered that the quality of the SiC bulk crystal is  
deteriorated substantially when the carrier density  
15 therein is increased beyond the value of  $1 \times 10^{20}\text{cm}^{-3}$ .  
Because of the poor quality of the SiC substrate 1,  
the experiment was not possible in the range of the  
carrier density exceeding the foregoing value of  $1 \times$   
 $10^{18}\text{cm}^{-3}$ .

20 Summarizing above, it is concluded that the  
n-type SiC substrate 1 preferably has the carrier  
density in the range between about  $1 \times 10^{18}\text{cm}^{-3}$  and  $1$   
 $\times 10^{20}\text{cm}^{-3}$ . When the carrier density is reduced below  
the foregoing value of  $1 \times 10^{18}\text{cm}^{-3}$ , the AlGaN/SiC  
25 interface resistance increases sharply. When the  
carrier density exceeds the value of  $1 \times 10^{18}\text{cm}^{-3}$ , on  
the other hand, the quality of the SiC substrate 1 is  
deteriorated.

Next, in the third-series experiment, an  
30 investigation was made on the effect of the Al content  
x in the n-type AlGaN buffer layer 2 on the AlGaN/SiC  
interface resistance. In the third-series experiment,  
the carrier density in the n-type SiC substrate 1 was  
set to about  $1 \times 10^{18}\text{cm}^{-3}$  and the carrier density in  
35 the n-type AlGaN buffer layer 2 was set to about  $5 \times$   
 $10^{18}\text{cm}^{-3}$ .

FIG.4 shows the AlGaN/SiC interface

1 resistance of the n-type AlGaN buffer layer 2 for the  
case in which the Al content  $x$  of the buffer layer 2,  
represented as  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ , is changed variously,  
wherein the horizontal axis represents the  
5 compositional parameter  $x$  in terms of atomic percent,  
while the vertical axis represents the AlGaN/SiC  
interface resistivity.

As can be seen from FIG.4, the experimental  
points are aligned on two lines,  $r_5$  and  $r_6$ , wherein  
10 the AlGaN/SiC interface resistivity is represented by  
the line  $r_5$  having a gentle gradient when the  
compositional parameter  $x$  is smaller than about 9%.  
When the compositional parameter  $x$  increased beyond  
the value of about 9%, on the other hand, the  
15 interface resistivity is represented by the line  $r_6$   
having a steeper gradient. Further, the interface  
resistivity increases with the compositional parameter  
 $x$  representing the Al content in the AlGaN buffer  
layer 2 in any of the lines  $r_5$  and  $r_6$ . Thus, from the  
20 result of FIG.4, it is preferable that the Al content  
 $x$  in the n-type AlGaN buffer layer 2 is set smaller  
than 9%.

In the foregoing first through third series  
experiments, the formation of the n-type AlGaN buffer  
25 layer 2 was conducted by an MOVPE process. On the  
other hand, it is believed that a similar result would  
be obtained also when the buffer layer 2 is formed by  
other deposition process such MBE (molecular beam  
epitaxy), as the value of the interface resistivity is  
30 primarily controlled by the band structure and the  
impurity concentration level.

Conventionally, the epitaxial growth of a  
GaN layer or a mixed crystal layer of GaN has been  
conducted by setting the pressure to about 100 Torr  
35 when the growth is made by MOVPE. In the foregoing  
experiments, the inventor of the present invention has  
discovered that it is necessary to increase the Al

1 content x in the n-type AlGaN buffer layer 2, which is  
grown directly on the SiC substrate 1, to be larger  
than 8% in order to obtain a flat and smooth top  
surface. Further, the inventor of the present  
5 invention has discovered that a flat and smooth top  
surface can be obtained for the n-type AlGaN buffer  
layer 2 even when the Al content x therein is smaller  
than 8%, by reducing the pressure in the MOVPE  
process.

10 FIG.5 shows the minimum Al content x needed  
for obtaining a planar and smooth top surface for the  
n-type AlGaN buffer layer 2, grown on the n-type SiC  
substrate 1 by the MOVPE process, as a function of the  
pressure used in the MOVPE process. More in detail,  
15 the horizontal axis of FIG.5 represents the pressure  
represented in Torr, while the vertical axis  
represents the minimum Al content x in terms of  
percent. In FIG.5, the horizontal axis and the  
vertical axis are represented in a linear scale.

20 Referring to FIG.5, it will be noted that  
the minimum Al content x needed for obtaining a flat  
and smooth top surface for the AlGaN buffer layer 2  
decreases gradually with decreasing pressure used in  
the MOVPE process along a line  $r_7$ . In other words,  
25 the relationship of FIG.5 represents the fact that the  
desired flat and smooth top surface can be obtained  
for the n-type AlGaN buffer layer 2 even when the Al  
content therein is small, by decreasing the pressure  
in the MOVPE process.

30 In the representation of FIG.5, it should be  
noted that the Al content in the vertical axis may  
contain an error of about  $\pm 1\%$ . Thus, the deviation of  
the experimental point for the pressure of 20 Torr  
from the line  $r_7$  may or may not be the result of the  
35 error. It should be noted that the experimental  
points for the pressure of 100 Torr, 70 Torr and 50  
Torr are aligned on the line  $r_7$ .

1        In the description hereinafter, it is noted  
that the value  $x$ , indicative of the Al content in the  
AlGaN buffer layer 2 and represented in terms of  
percent, includes an error of about  $\pm 1\%$ .

5        From the result of FIG.5, it is concluded  
that the MOVPE process is conducted under a pressure  
of about 90 Torr or less when to grow an AlGaN layer  
on an SiC substrate with a flat and smooth top surface  
and with an Al content of about 8%. In order to grow  
10      a similar AlGaN layer with an Al content of about 6%,  
on the other hand, it is preferable to conduct the  
MOVPE process under a pressure of about 70 Torr or  
less. Further, in order to grow a similar AlGaN layer  
15      with an Al content of about 4%, it is preferable to  
conduct the MOVPE process under a pressure of about 50  
Torr or less. In order to grow a similar AlGaN layer  
with an Al content of about 2%, it is preferable to  
conduct the MOVPE process under a pressure of about 20  
Torr or less.

20       In view of the foregoing experimental  
results, it is possible to grow an n-type AlGaN buffer  
layer on an n-type SiC substrate epitaxially such that  
the AlGaN/SiC interface resistance is minimized and  
simultaneously the AlGaN buffer layer has a flat and  
25      smooth top surface. By growing epitaxial layers on  
the SiC substrate thus covered by the buffer layer, it  
is possible to form a GaN-family laser diode having a  
reduced threshold voltage. As a result of the use of  
30      the SiC substrate, it should be noted that the laser  
diode includes the n-side electrode formed on the SiC  
substrate, similarly to a usual edge-emission type  
laser diode.

FIGS.6A and 6B show the construction of a  
GaN-family laser diode 100 based on the foregoing  
35      experiments.

Referring to FIG.6A, the GaN-family laser  
diode 100 is constructed on an n-type 6H-SiC substrate

1       31 having a Wurtzite structure and defined by a  
     (0001)Si top surface. The substrate 31 is doped by n  
     to a carrier density of about  $8 \times 10^{17} \text{ cm}^{-3}$ , for  
     example.

5       On the foregoing (0001)Si surface of the  
     substrate 31, there is provided an n-type epitaxial  
     structure 30, and an active layer structure 40 is  
     formed on the epitaxial structure 30. Further,  
     another epitaxial structure 50 of the p-type is formed  
10      on the active layer structure 40.

It should be noted that the n-type epitaxial  
structure 30 includes a buffer layer 32 of n-type  
AlGaN having a composition of  $\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$  grown  
epitaxially on the (0001)Si surface of the substrate  
15      31, another buffer layer 33 of n-type GaN formed  
     epitaxially on the buffer layer 32, a cladding layer  
     34 of n-type AlGaN having a composition of  
      $\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$  grown epitaxially on the buffer layer  
     33, and an optical waveguide layer 35 of n-type GaN  
20      grown epitaxially on the cladding layer 34. The  
     buffer layer 32 of the n-type AlGaN may have a  
     thickness of about 0.15  $\mu\text{m}$  and is doped with Si to an  
     impurity concentration level of about  $8 \times 10^{18} \text{ cm}^{-3}$ .  
     The buffer layer 33, in turn, has a thickness of about  
25      0.1  $\mu\text{m}$  and is doped with Si to an impurity  
     concentration level of about  $3 \times 10^{18} \text{ cm}^{-3}$ . Further,  
     the cladding layer 34 of n-type AlGaN has a thickness  
     of typically about 0.5  $\mu\text{m}$  and is doped with Si to an  
     impurity concentration level of about  $3 \times 10^{18} \text{ cm}^{-3}$ .  
30      The optical waveguide layer 35 of n-type GaN has a  
     thickness of about 0.1  $\mu\text{m}$  and is doped with Si to a  
     concentration level of about  $3 \times 10^{18} \text{ cm}^{-3}$ .

The active layer structure 40 forms an MQW  
(multiple quantum well) structure formed of alternate  
35      and repetitive stacking of a quantum well layer of  
     undoped InGaN having a composition of  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$   
     and a barrier layer of undoped InGaN having a

1 composition of  $In_{0.03}Ga_{0.97}N$ , wherein the quantum well  
layer typically has a thickness of about 4.0 nm while  
the barrier layer has a thickness of typically about  
5.0 nm. In one example, the quantum well layer is  
5 repeated three times and there are provided four  
barrier layers in all in the MQW active layer  
structure 40.

The p-type epitaxial structure 50 includes  
an electron blocking layer 51 of p-type AlGaN having a  
10 composition of  $Al_{0.18}Ga_{0.82}N$  grown epitaxially on the  
active layer structure 40, an optical waveguide layer  
52 of p-type GaN formed epitaxially on the electron  
blocking layer 51, a cladding layer 53 of p-type AlGaN  
having a composition of  $Al_{0.09}Ga_{0.91}N$  grown  
15 epitaxially on the optical waveguide layer 52, and a  
contact layer 54 of p-type GaN grown epitaxially on  
the cladding layer 53. The electron blocking layer 51  
of p-type AlGaN has a large bandgap and blocks the  
electrons overflowing from the active layer structure  
20 40 underneath.

Typically, the electron blocking layer 51  
has a thickness of about 20 nm and is doped with Mg to  
an impurity concentration level of about  $5 \times 10^{19} \text{ cm}^{-3}$ .  
The GaN optical waveguide layer 52, in turn, has a  
25 thickness of about 0.1  $\mu\text{m}$  and is doped with Mg to an  
impurity concentration level of about  $5 \times 10^{19} \text{ cm}^{-3}$ .  
Further, the cladding layer 53 of p-type AlGaN has a  
thickness of typically about 0.5  $\mu\text{m}$  and is doped with  
Mg to an impurity concentration level of about  $5 \times$   
30  $10^{19} \text{ cm}^{-3}$ . The contact layer 54 of p-type GaN has a  
thickness of about 0.2  $\mu\text{m}$  and is doped with Mg to a  
concentration level of about  $5 \times 10^{19} \text{ cm}^{-3}$ . By  
providing the contact layer 54, the contact resistance  
of a p-side electrode provided thereon is reduced.

35 The foregoing epitaxial layers are grown on  
the SiC substrate 31 by MOVPE under a reduced pressure  
of about 100 Torr. In the MOVPE process, TMG or TEG

1      is used for the gaseous source of Ga, TMA is used for  
the gaseous source of Al, TMI (trimethylindium) is  
used for the gaseous source of In, and NH<sub>3</sub> is used for  
the source of N, together with the dopant gas of SiH<sub>4</sub>  
5      or biscyclopentadienyl magnesium (Cp<sub>2</sub>Mg).

The n-type SiC substrate 31 may be formed  
from a bulk crystal ingot of n-type SiC grown by an  
improved Rayleigh method that uses a seed crystal.

It should be noted that the n-type epitaxial  
10     structure 30 may be formed by conducting the MOVPE  
process at a substrate temperature of 1090°C with a  
growth rate of about 2 μm/H. On the other hand, the  
MQW structure of the active layer structure 40 may be  
formed by conducting the MOVPE process at a substrate  
15     temperature of 780°C with a growth rate of about 0.3  
μm/H. Further, the p-type epitaxial structure 50 may  
be formed by conducting the MOVPE process at a  
substrate temperature of 1130°C with a growth rate of  
about 1 μm/H.

20     In the GaN-family laser diode 100 thus  
obtained, it should be noted that the AlGaN/SiC  
interface resistance at the interface between the n-  
type SiC substrate 31 and the n-type AlGaN buffer  
layer 32 is successfully suppressed in view of the  
25     fact that the n-type AlGaN buffer layer 32 having the  
composition of Al<sub>0.09</sub>Ga<sub>0.91</sub>N contains the n-type  
carriers with the carrier density of about 8 × 10<sup>18</sup> cm<sup>-3</sup>. See the diagram of FIG.2B. It should be noted  
that the thickness of the n-type SiC substrate 31 may  
30     be reduced, from an initial thickness of about 200 μm,  
to about 100 μm by polishing the rear surface thereof.

After the formation of the epitaxial  
structures 30, 40 and 50 on the Si substrate 31, the  
epitaxial structures are subjected to a dry etching  
35     process and a mese structure having a width of 3 - 5  
μm, typically 3.5 μm, is formed to extend in the axial  
direction of the laser diode with a height of about

1        0.4  $\mu\text{m}$ . As a result of the mesa formation, there is  
formed a refractive optical guide structure in the  
cladding layer 53 wherein the optical guide structure  
thus formed controls the transverse mode of laser  
5        oscillation.

After the mesa formation, an insulation film  
61 of  $\text{SiO}_2$  is formed so as to cover the mesa structure  
thus formed in the cladding layer 53 and the contact  
layer 54, followed by formation of a contact window in  
10      the insulation film 61 so as to expose the contact  
layer 54. The contact window thus formed may have a  
width of 1 - 4  $\mu\text{m}$ .

After the step of formation of the contact  
window, an n-side electrode 63 is formed on the SiC  
15      substrate 31 by depositing a Ni layer, a Ti layer and  
a Au layer consecutively on the bottom surface of the  
SiC substrate. Further, a p-side electrode 62 is  
formed on the mesa structure by depositing a Ni layer,  
a Ti layer and a Au layer consecutively.

20      The structure thus obtained is then  
subjected to a cleaving process in the direction  
perpendicular to the elongating direction of the mesa  
structure, in other words the axial direction of the  
laser diode, to form a ridge-type cavity having a  
25      length of about 700  $\mu\text{m}$  as represented in FIG.6B. It  
should be noted that the ridge-type cavity extends in  
the <1100> direction of the SiC substrate 31, while  
the cleavage surface has an orientation of [1100]. In  
the structure of FIG.6B, mirrors HR are formed on the  
30      cleaved surfaces.

It was confirmed that the GaN-family laser  
diode 100 thus formed oscillates at the optical  
wavelength of 420 nm when driven by a pulse generator  
at a frequency of 1 kHz - 10 kHz. Thereby, it was  
35      observed that the threshold current is about 500 mA  
and the threshold voltage is about 15V.

For the sake of comparison, a laser diode

1 similar to the GaN-family laser diode 100 was  
2 fabricated in which the carrier density of the n-type  
3 AlGaN buffer layer 32 is set to  $3 \times 10^{18} \text{ cm}^{-3}$  while  
4 maintaining the composition of the buffer layer 32 to  
5  $\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$ . In this experiment, although it was  
confirmed that the laser diode oscillates at the  
optical wavelength of 420 nm, the threshold voltage  
has increased to 22V. The threshold current remained  
the same and took the value of 500 mA. The foregoing  
10 result indicates that the threshold voltage of the  
laser diode is reduced from 22V to 15V, by increasing  
the carrier density in the n-type AlGaN buffer layer  
32 having the composition of  $\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$  from  $3 \times$   
 $10^{18} \text{ cm}^{-3}$  to  $8 \times 10^{18} \text{ cm}^{-3}$ .

15 Further, another experiment was conducted by  
fabricating a laser diode similar to the laser diode  
100 except that the carrier density in the n-type SiC  
substrate 31 is increased from  $8 \times 10^{17} \text{ cm}^{-3}$  to  $4 \times$   
 $10^{18} \text{ cm}^{-3}$ .

20 It was confirmed that the laser diode thus  
formed oscillates at the optical wavelength of 420 nm  
similarly to the laser diode 100 and that the  
threshold voltage was decreased to 12V, indicating a  
further decrease by 3V as compared with the laser  
25 diode 100. The threshold current remained the same.

In view of the relationship of FIG.2B, it is  
expected that the threshold voltage may be decreased  
further by increasing the carrier density in the n-  
type AlGaN buffer layer 32. Further, the relationship  
30 of FIG.4 indicates that the AlGaN/SiC interface  
resistance, and hence the threshold voltage of the  
laser diode, is reduced further by reducing the Al  
content in the AlGaN buffer layer 32 below the value  
of 0.09.

35 In order to maintain the flat and smooth  
surface for the AlGaN buffer layer 32 for the case in  
which the Al content is reduced, it is preferable to

1     conduct the MOVPE process for forming the AlGaN buffer  
layer 32 under a reduced pressure environment, in view  
of the relationship of FIG.5. For example, the buffer  
layer 32 may be formed to have a composition  
5      $\text{Al}_{0.04}\text{Ga}_{0.96}\text{N}$  in place of the composition of  
 $\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$  by conducting the MOVPE process under  
the pressure of 40 Torr. Other epitaxial layers are  
formed similarly to the case of the laser diode 100.

When the Si concentration level of  $8 \times$   
10 10<sup>18</sup> cm<sup>-3</sup> is used in the n-type AlGaN buffer layer 32  
in combination with the foregoing composition of  
 $\text{Al}_{0.04}\text{Ga}_{0.96}\text{N}$ , it is expected that the threshold  
voltage decreased to about 10V. By further reduction  
of the Al content in the n-type AlGaN buffer layer 32,  
15     the AlGaN/SiC interface resistance, and hence the  
threshold voltage, would be reduced further.

[SECOND EMBODIMENT]

During the experimental investigation on the  
20     GaN-family laser diode 100 described with reference to  
FIGS.6A and 6B, the inventor of the present invention  
has discovered a relationship shown in FIG.7 between  
the threshold current and the thickness of the  
epitaxial layers interposed between the SiC substrate  
25     41 and the active layer structure 40, wherein the  
vertical axis represents the threshold current density  
of the laser diode while the horizontal axis  
represents the total thickness of the epitaxial layers  
interposed between the SiC substrate 31 and the active  
30     layer structure 40.

Referring to FIG.7, the threshold current  
generally decreases with increasing thickness in the  
epitaxial layers interposed between the substrate 31  
and the active layer 40 and that the decrease occurs  
35     sharply until the total thickness of the epitaxial  
layers reach the value of about 1.6  $\mu\text{m}$ .

While the reason of this phenomenon is not

1 clearly understood, it is probable that the defect  
density in the epitaxial layers decreases with  
increasing total thickness of the epitaxial layers  
between the substrate 31 and the active layer  
5 structure 40.

Thus, in view of the relationship of FIG.7,  
it is concluded that the threshold current of the  
laser diode can be reduced by increasing the total  
thickness of the epitaxial layers interposed between  
10 the substrate 31 and the active layer structure 40.  
On the other hand, there arises a problem of cracking  
in the epitaxial structure 30, 40 or 50 when the  
foregoing total thickness is increased excessively,  
probably due to the tensile stress caused as a result  
15 of the difference in thermal expansion between the SiC  
substrate 31 and the nitride epitaxial layers thereon.

The inventor of the present invention has  
discovered that the cracking of the epitaxial  
structures is effectively suppressed by setting the Al  
20 content  $y$  of the lower cladding layer 34 of n-type  
AlGaN having a composition represented as  $\text{Al}_y\text{Ga}_{1-y}\text{N}$ ,  
to be smaller than the Al content  $x$  of the foregoing  
n-type AlGaN buffer layer 32, of which composition is  
represented as  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  ( $y < x$ ). Further, the  
25 inventor of the present invention has discovered that  
the problem of cracking of the epitaxial layers is  
further suppressed by setting the Al content  $z$  of the  
upper cladding layer 53 of p-type AlGaN having a  
composition represented as  $\text{Al}_z\text{Ga}_{1-z}\text{N}$ , to be smaller  
30 than the Al content  $y$  in the lower cladding layer 34  
( $z < y$ ). It is believed that the foregoing  
suppression of the crack formation in the epitaxial  
layers is achieved as a result of cancellation of the  
tensile stress, which is induced in the epitaxial  
35 layer by the differential thermal expansion of the SiC  
substrate 31 and the epitaxial layers, by a  
compressive stress. It should be noted that the

1 foregoing compressive stress is induced in the  
epitaxial layers including the buffer layer 32 and the  
cladding layers 34 and 53 as a result of the  
difference in the lattice constant between the SiC  
5 substrate 31 and the epitaxial layers thereon.

FIG.8 shows the construction of a laser  
diode 200 according to a second embodiment of the  
present invention, wherein those parts corresponding  
to the part described previously are designated by the  
10 same reference numerals and the description thereof  
will be omitted.

Referring to FIG.8, the laser diode 200 has  
a construction in which the GaN buffer layer 33 is  
omitted, and the AlGaN buffer layer 32, the AlGaN  
15 cladding layer 34 and the GaN optical waveguide layer  
35 are formed to have respective thicknesses of 1.0  
 $\mu\text{m}$ , 1.5  $\mu\text{m}$  and 0.1  $\mu\text{m}$ . As a result, the total  
thickness of the epitaxial layers interposed between  
the SiC substrate 31 and the active layer structure 40  
20 takes a value of 2.6  $\mu\text{m}$ , and the threshold current  
density of laser oscillation 200 is reduced to about 7  
- 8  $\text{kA}/\text{cm}^2$ .

In the present embodiment, it should be  
noted that the lower cladding layer 34 of n-type AlGaN  
25 contains Al with an atomic fraction  $y$  of 0.10 ( $y =$   
0.10), while this value of the Al content  $y$  is smaller  
than the Al content  $x$  of 0.15 ( $x = 0.15$ ) of the n-type  
AlGaN buffer layer 32. Further, it should be noted  
that the upper cladding layer 53 of p-type AlGaN  
30 contains Al with an atomic fraction  $z$  of 0.08 ( $z =$   
0.08), while this value  $z$  of the Al content of the  
upper cladding layer 53 is smaller than the foregoing  
value  $y$  for the lower cladding layer 34.

As a result of the foregoing construction,  
35 the laser diode 200 of the present embodiment  
successfully eliminates the crack formation in the  
epitaxial layers.

1        Other features of the present embodiment are  
substantially the same as those of the laser diode 100  
described previously and further description thereof  
will be omitted.

5        FIG.9 shows the construction of a laser  
diode 210 corresponding to a modification of the laser  
diode 210 of the present embodiment, wherein those  
parts corresponding to the parts described previously  
are designated by the same reference numerals and the  
10      description thereof will be omitted.

In the present modification, the buffer  
layer 32, the cladding layer 34 and the optical  
waveguide layer 35 are formed to have respective  
thicknesses of 0.35  $\mu\text{m}$ , 1.15  $\mu\text{m}$  and 0.1  $\mu\text{m}$ , thus  
15      leading to the total thickness of 1.6  $\mu\text{m}$  for the  
epitaxial layers interposed between the SiC substrate  
31 and the active layer structure 40. In the present  
modification, the buffer layer 32 and the lower  
cladding layer 34 are formed to have the same Al  
20      content of 0.10 for the compositional parameters x and  
y, while the upper cladding layer 53 contains Al with  
a reduced content of 0.08 for the compositional  
parameter z. Thereby, the problem of cracking of the  
epitaxial layers is suppressed effectively also in the  
25      present modification.

[THIRD EMBODIMENT]

In the ridge-type laser diode 100, 200 or  
210 described before, the control of transversal mode  
30      laser oscillation in the active layer structure 40 is  
achieved by forming a mesa structure in the upper  
cladding layer 53 as explained before.

In the ridge-type laser diode having such a  
structure, it is necessary to form the mesa structure  
35      to have a width of less than about 2  $\mu\text{m}$  in order to  
achieve a satisfactory control of the transversal mode  
oscillation, while the formation of such a narrow mesa

1     structure has been difficult. Further, the foregoing  
conventional ridge-type laser diode has a drawback in  
that the contact area between the electrode 62 and the  
contact layer 54 is reduced inevitably when the width  
5     of the mesa structure is thus reduced below 2  $\mu\text{m}$ . It  
should be noted that the width of the contact window  
formed in the  $\text{SiO}_2$  film 61 is reduced together with  
the width of the mesa structure, while formation of  
such a very small contact window in the  $\text{SiO}_2$  film 61  
10    on the mesa structure raises various problems.

Further, the ridge-type laser diodes have a  
further drawback in that the confinement of the  
optical radiation inside the active layer structure 40  
in the vertical direction tends to become weak and  
15    insufficient. In order to realize a satisfactorily  
strong optical confinement in the active layer  
structure 40, it is necessary to increase the  
thickness of the upper cladding layer 53 further,  
while such an increase of thickness of the upper  
20    cladding layer 53 tends to cause a cracking therein.  
It should be noted that the cladding layer 53 has a  
lattice constant different from that of the buffer  
layer 32. In view of insufficient optical confinement  
25    in the active layer structure 40, the ridge-type laser  
diodes including the laser diodes 100, 200 and 210  
tend to show the problem of optical loss caused by the  
electrode 62 or poor far-field pattern (FFP) in the  
optical beam produced by the laser diode.

FIGS.10A and 10B show a fabrication process  
30    of a laser diode 300 wherein the foregoing problems  
are eliminated, wherein those parts corresponding to  
the parts described previously are designated by the  
same reference numerals and the description thereof  
will be omitted.

35    Referring to FIG.10A, the laser diode 300 is  
constructed on the n-type SiC substrate 31 carrying  
thereon the n-type epitaxial structure 30, the active

1 layer structure 40 and the p-type epitaxial structure  
50 similarly to the laser diodes of the previous  
embodiments, wherein the mesa formation in the upper  
cladding layer 53 or the contact layer 54 forming a  
5 part of the p-type epitaxial structure 50 is omitted.  
It should be noted that the n-type epitaxial structure  
30 includes the n-type nitride layers 32 - 35 while  
the p-type epitaxial structure includes the p-type  
nitride layers 51 - 54 similarly as before. As a  
10 result, the contact layer 54 has a flat top surface  
and an insulation film 301 of SiO<sub>2</sub> is formed on the  
flat top surface of the contact layer 54 by a high-  
temperature CVD process with a thickness of about 300  
nm.

15 The SiO<sub>2</sub> film 301 is then patterned by a  
photolithographic process using HF as an etchant to  
form a stripe opening 301W in the SiO<sub>2</sub> film 301 with a  
width of about 1 μm, wherein the stripe opening 301W  
is formed so as to extend in the axial direction of  
20 the laser diode 300 coincident with the <1100>  
direction of the SiC substrate 31.

Next, in the step of FIG.10B, the deposition  
of a p-type AlGaN layer having a composition of  
Al<sub>0.09</sub>Ga<sub>0.91</sub>N is made on the exposed part of the GaN  
25 cap layer 54 exposed at the foregoing stripe opening  
301W by an MOVPE process while using the SiO<sub>2</sub> film 301  
as a mask, to form a third cladding layer 302 with a  
thickness of about 1.4 μm. It should be noted that  
the MOVPE process is conducted under a condition  
30 similar to the condition used for forming the  
epitaxial layers in the p-type epitaxial structure 50.  
The third cladding layer 302 thus grows not only in the  
upward direction but also in lateral directions to  
form a ridge structure covering the insulation film  
35 301 and extending thereon in the axial direction of  
the laser diode.

Next, in the step of FIG.10B, a contact

1 layer 303 of p-type GaN is formed on the third  
cladding layer 302 by an MOVPE process with a  
thickness of about 0.2  $\mu\text{m}$  so as to cover both side  
walls and a top surface thereof continuously, and the  
5 electrode 62 is deposited so as to cover the contact  
layer 303 continuously over a part corresponding to  
the side walls and the top surface of the underlying  
third cladding layer 302. Further, the bottom surface  
10 of the n-type SiC substrate 31 is polished and the  
electrode 63 is formed on the bottom surface of the  
SiC substrate 31 thus polished, similarly to the  
embodiments described before.

According to the laser diode 300 of the  
present embodiment, the photolithographic patterning  
15 process of the insulation film 301 is conducted in the  
step of FIG.10A on the flat, planar principal surface  
of the GaN cap layer 54. Thereby, the patterning  
process is under an ideal condition with an excellent  
precision and the stripe opening 301W is formed  
20 relatively easily to have a width of less than 1  $\mu\text{m}$ .

In the present embodiment, it should be  
noted that the cap layer 54 of GaN is provided for  
preventing the oxidation of the AlGaN cladding layer  
25 53 when forming the insulation film 301. The  
insulation film 301 is by no means limited to  $\text{SiO}_2$  but  
other materials such as  $\text{SiN}$  or  $\text{Al}_2\text{O}_3$  may also be used.

It should be noted that the structure of the  
present embodiment is applicable also to the  
conventional laser diode constructed on a sapphire  
30 substrate such as the one described with reference to  
FIG.1. When using a sapphire substrate, the stripe  
opening 301W is formed in the insulation film 301 so  
as to extend in the <11Z0> direction of the sapphire  
substrate corresponding to the <iI> direction of a GaN  
35 crystal.

According to the laser diode 300 of the  
present embodiment, in which the electrode 62 covers

1 the top surface and both side walls of the third  
cladding layer 302 continuously via the contact layer  
303, the contact resistance of the electrode 62 is  
reduced substantially. Further, in view of the fact  
5 that the injection of carriers (holes) into the active  
layer structure 40 is restricted to the foregoing  
elongating stripe opening 301W, the desired current  
confinement in the active layer structure 40 is  
achieved effectively without restricting the width of  
10 the cladding layer 302 strictly. Thereby, an  
effective control of the transverse mode becomes  
possible.

As the cladding layer 302 is formed as a  
result of the selective growth of the AlGaN layer  
15 occurring in the narrowly confined stripe opening  
301W, there occurs no substantial problem of  
relaxation of crystal lattice in the AlGaN cladding  
layer 302 and the crack formation does not occur in  
the cladding layer 302 even when the third cladding  
20 layer 302 is formed to have an increased thickness.  
Thereby, an excellent optical confinement is realized  
in the vertical direction and the far-field pattern of  
the laser diode is improved substantially. Further,  
the problem of optical loss caused by the electrode 62  
25 is also reduced.

In the step of FIG.10B, there may be a case  
in which particles are formed on the insulation film  
301 during the process of forming the cladding layer  
302 or the contact layer 303 by the selective growth  
30 process. It should be noted that the insulation film  
301 is used in the foregoing selective growth process  
as a mask. When there occurs such a deposition of  
particles on the insulation film 301, the adherence of  
the electrode 62 may be deteriorated.

35 In order to avoid the foregoing risk of  
deterioration of adherence of the electrode 62, the  
 $\text{SiO}_2$  film 301 may be removed by a wet etching process

1 after the formation of the cladding layer 301 and the  
contact layer 303 by using a suitable etchant such as  
HF. As a result of removal of the SiO<sub>2</sub> film 301, the  
particles deposited thereon are also removed.

5 FIG.11 shows the construction of a laser  
diode 310 thus formed according to a modification of  
the present embodiment.

10 Referring to FIG.11, the third cladding  
layer 302 has a T-shaped form having a reduced width  
at the bottom part thereof similarly to the structure  
of FIG.10B, wherein it should be noted that the SiO<sub>2</sub>  
film 301 of FIG.10B is replaced with an air gap 301G  
cutting into the cladding layer 302 from both lateral  
sides thereof at the bottom part of the cladding layer  
15 302. Further, an SiO<sub>2</sub> film similar to the SiO<sub>2</sub> film  
61 is provided so as to cover the top surface and both  
side walls of the cladding layer 302 wherein the SiO<sub>2</sub>  
film 61 covers the exposed top surface of the contact  
layer 54. The contact laser 61 is formed with an  
20 opening exposing the GaN contact layer 303 covering  
the top surface of the third cladding layer 302 and  
the electrode 62 makes an ohmic contact with the  
exposed top surface of the third cladding layer 302.

Typically, the SiO<sub>2</sub> film 61 is formed by a  
25 vapor phase deposition process such as a high-  
temperature CVD process and may penetrate into the air  
gap 301G. Thereby, the air gap 301G may be filled  
entirely or partially by SiO<sub>2</sub> forming the SiO<sub>2</sub> film  
61.

30 In the laser diode 300 or 310 of the present  
embodiment, it is possible to eliminate the contact  
layer 303.

[FOURTH EMBODIMENT]

35 FIG.12A is a plan view showing the  
insulation film 301 used as a mask in the foregoing  
fabrication process of the laser diode 300 or 310,

1 when forming the cladding layer 302 or 303 by a  
selective growth process.

Referring to FIG.12A, the insulation film  
301 includes a number of linearly extending stripe  
5 openings each having a width of about 1  $\mu\text{m}$ . The  
stripe openings are repeated with an interval of about  
300  $\mu\text{m}$ , and thus, there is formed a wide area of  $\text{SiO}_2$   
between one stripe opening and an adjacent stripe  
opening.

10 Thus, it will be easily understood that  
there occur an extensive formation of particles on the  
mask when the insulation film 301 of FIG.12A is used  
for the mask during the MOVPE process for forming the  
third cladding layer 302 or the contact layer 303.

15 In the present embodiment, the foregoing  
problem of deposition of particles on the mask is  
eliminated by using a mask 301A shown in FIG.12B.

Referring to FIG.12B, it will be noted that  
a pair of linearly extending insulation stripes 301a  
20 and 301b each having a width of 6  $\mu\text{m}$  are disposed  
adjacent with each other to form a mask pattern 301c,  
with a gap 301n of about 1  $\mu\text{m}$  formed between the  
insulation stripes 301a and 301b forming the mask  
pattern 301c, wherein the foregoing mask pattern 301c  
25 thus formed is repeated a number of times with a pitch  
of 300  $\mu\text{m}$ . In the mask 301A thus including the  
repetition of the mask patterns 301c, it should be  
noted that the underlying GaN contact layer 54 is  
exposed between a mask pattern 301c and an adjacent  
30 mask pattern 301c, and the problem of particle  
formation is effectively eliminated. Instead of  
forming particles, the source elements supplied during  
the MOVPE process for forming the p-type AlGaN  
cladding layer 302 or the p-type GaN contact layer 303  
35 form an epitaxial layer of p-type AlGaN or p-type GaN  
on the exposed surface of the GaN contact layer 54.

FIG.13 shows the construction of a laser

1 diode 400 that uses the mask 301A of FIG.12B for the  
selective growth process of the third cladding layer  
302 and the contact layer 303 according to a fourth  
embodiment of the present invention, wherein those  
5 parts corresponding to the parts described previously  
are designated by the same reference numerals and the  
description thereof will be omitted.

Referring to FIG.13, the mask 301A is formed  
on the contact layer 54 of p-type GaN, and the  
10 cladding layer 302 of p-type AlGaN and the contact  
layer 303 of p-type GaN are formed consecutively on  
the contact layer 54 in correspondence to the stripe-  
formed gap 301n of the mask pattern 301c, by  
conducting the MOVPE process while using the mask 301A  
15 as a mask. Simultaneously, an epitaxial layer 302A of  
p-type AlGaN having a composition substantially  
identical with the composition of the cladding layer  
302 is formed outside the mask pattern 301c, and  
another epitaxial layer 303A of p-type GaN having a  
20 substantially identical composition with the  
composition of the contact layer 303 is formed on the  
epitaxial layer 302A. Thereby, the epitaxial  
structure including the epitaxial layers 302A and 303A  
is separated from the structure formed of the third  
25 cladding layer 302 and the contact layer 303 by a  
recess exposing the mask 301A.

It should be noted that the epitaxial layer  
303A is covered by another SiO<sub>2</sub> film 304, wherein the  
SiO<sub>2</sub> film 304 includes an opening formed in  
30 correspondence to the recess part so as to expose the  
contact layer 303, and an electrode corresponding to  
the electrode 62 is formed on the SiO<sub>2</sub> film 304 so as  
to fill the foregoing recess. It should be noted that  
the SiO<sub>2</sub> film 304 is formed to have a thickness of  
35 about 200 nm by a high-temperature CVD process, and  
the foregoing opening is formed in the SiO<sub>2</sub> film 304  
by a wet etching process using HF.

1        As explained already, the laser diode 400 of  
the present embodiment minimizes the formation of  
particles on the mask 301A and the yield of production  
of the laser diode is improved substantially. As the  
5        laser diode 400 of FIG.13 allows the electrode 62 to  
have a large area and a substantially flat top  
surface, mounting process of the laser diode 400 is  
facilitated substantially.

10      [FIFTH EMBODIMENT]

As explained already, the selective growth  
process used in the fabrication process of the laser  
diode 300, 310 or 400 tends to cause the problem of  
deposition of particles on the insulation mask. This  
15     problem of particle formation becomes particularly  
serious in the process of forming the cladding layer  
302 of AlGaN. It should be noted that the AlN  
component included in the AlGaN cladding layer 301 has  
a tendency of preferential deposition on an SiO<sub>2</sub> film  
20     that forms the mask 301, while the AlN component thus  
deposited tend to act as a nucleus for formation of  
the AlGaN cladding layer 301.

In the experimental investigation that  
constitutes the basis of the present invention, the  
25     inventor of the present invention has discovered that  
the formation of particles on an SiO<sub>2</sub> mask is  
effectively suppressed in the selective growth process  
of AlGaN conducted by an MOVPE process, by supplying  
the gaseous source of the elements together with a gas  
30     containing halogen.

FIGS.14A - 14F explain the foregoing  
experiments conducted by the inventor of the present  
invention.

Referring to FIG.14A, a 6H-SiC substrate 501  
35     is cleaned in an organic solvent and then in water,  
and the substrate 501 thus processed is then immersed  
in a bath of HF for about 1 minute.

1       The substrate 501 thus processed is then  
introduced into a reaction chamber of an MOVPE  
apparatus so as to expose a (0001)Si surface thereof  
on which the deposition of epitaxial layers is to be  
5       made. After evacuating the reaction chamber, the  
native oxide film is removed from the surface of the  
SiC substrate 501 by processing the substrate 501 at  
1080°C in a hydrogen atmosphere for about 5 minutes.  
10      Next, the substrate temperature is reduced to about  
1050°C, and an AlGaN film 502 is grown on the  
foregoing (0001)Si surface of the substrate 501 while  
supplying TMG, TMA and NH<sub>3</sub> with respective flow rates  
of 44 μmol/min, 8 μmol/min and 0.1 μmol/min, together  
15      with a carrier gas of H<sub>2</sub>. The foregoing source gases  
are applied directly to the substrate surface and the  
AlGaN film 502 is grown thereon with a thickness of  
about 1 μm.

20      Next, in the step of FIG.14B, the supply of  
TMG and TMA is interrupted and the substrate  
temperature is lowered to 600°C or lower while  
continuously directing the NH<sub>3</sub> gas to the substrate.  
Thereby, the atmosphere inside the reaction chamber is  
changed to N<sub>2</sub>. After cooling further to the room  
temperature, the substrate 501 is taken out from the  
25      deposition chamber, and an SiO<sub>2</sub> film 503 is formed on  
the foregoing AlGaN film 502 with a thickness of 0.2  
μm.

30      Next, in the step of FIG.14C, a resist film  
is formed on the SiO<sub>2</sub> film 503, followed by a  
 patterning process to form a resist pattern 504 having  
a width of 2 μm, such that the resist pattern 504 is  
repeated with a pitch of 30 μm.

35      Next, in the step of FIG.14D, the SiO<sub>2</sub> film  
is subjected to a wet etching process using HF as an  
etchant to form a line and space pattern exposing the  
AlGaN film 502. After removing the resist pattern 504  
by using an organic solvent, the substrate 501 is

1 returned to the reaction chamber of the MOVPE  
apparatus. The reaction chamber is then evacuated,  
and the native oxide film is removed from the exposed  
part of the AlGaN film 502 by applying a heat  
5 treatment process at 1050°C in H<sub>2</sub> atmosphere, while  
supplying NH<sub>3</sub>. Further, a selective epitaxial growth  
of an AlGaN film 505 is made on the exposed surface of  
the AlGaN film 502 by supplying TMG, TMA, CH<sub>3</sub>Cl and  
NH<sub>3</sub> with respective flow rates of 44 μmol/min, 8  
10 μmol/min, 52 μmol/min and 0.1 μmol/min, together with  
a carrier gas of H<sub>2</sub>.

In the step of FIG.14F, the substrate  
temperature is then lowered to below 600°C while  
supplying NH<sub>3</sub> to the reaction chamber, such that the  
15 atmosphere inside the reaction chamber is changed to  
the N<sub>2</sub> atmosphere. Thereafter, the substrate  
temperature is lowered to the room temperature.

According to the selective growth process of  
the present embodiment, the CH<sub>3</sub>Cl molecules supplied  
20 in the step of FIG.14F to the reaction chamber  
together with the gaseous source material release Cl  
atoms as a result of the pyro-decomposition process  
thereof, wherein the Cl atoms thus released suppresses  
the AlN formation on the exposed surface of the AlGaN  
25 film 502 by preferentially reacting with Al. The  
supply of CH<sub>3</sub>Cl is preferably made to the reaction  
chamber by a gas inlet different from the inlet used  
for introducing a gaseous source of group V element  
such as NH<sub>3</sub>. Thereby, the nuclei formation on the  
30 SiO<sub>2</sub> mask 503 is impeded and the deposition of  
polycrystalline or particulate precipitates on the  
mask 503 is suppressed.

It should be noted that the element that  
suppresses the AlN formation on the SiO<sub>2</sub> mask is by no  
35 means limited to Cl but other halogen element such as  
F can be used also for the same purpose. Further, the  
compound that is used as the carrier of the halogen

1 atom is by no means limited to CH<sub>3</sub>Cl but other halogen  
compounds, including a metal-organic compound  
containing halogen, may also be used.

5 It should be noted that the selective  
epitaxial growth process according to the present  
embodiment is applicable not only to the fabrication  
process of a ridge-type laser diode as described but  
the present embodiment is also applicable to general  
fabrication process of a semiconductor device that  
10 includes a selective growth of a nitride film of a  
group III element including Al.

[SIXTH EMBODIMENT]

In the GaN-family laser diodes 100, 200,  
15 300, 310 and 400 described heretofore, it should be  
noted that there is formed an electron blocking layer  
51 of AlN formed adjacent to the active layer  
structure 40, wherein the electron blocking layer 51  
is doped with Mg to a high concentration level and  
blocks the electrons that are injected into the active  
layer structure 40 and subsequently causing an  
overflow from the active layer structure 40 as a  
result of the large electric field formed in the p-  
type epitaxial structure 50. For this purpose, the  
20 electron blocking layer 51 is generally formed to have  
a composition that provides a large bandgap. Thus,  
the optical waveguide layer 52 of p-type GaN or the  
cladding layer 53 of p-type AlGaN is formed above the  
electron blocking layer 51. It should be noted that  
25 the p-type AlGaN cladding layer 53 has a relatively  
large resistivity, and because of this, the foregoing  
large electric is created.

FIG.15 shows the Mg concentration profile  
used in the GaN-family laser diode disclosed in the  
35 Japanese Laid-Open Patent Publication 10-56236 for the  
part located above the active layer structure. It  
should be noted that the GaN-family laser diode of

1 FIG.15 is formed on a sapphire substrate.

Referring to FIG.15, the laser diode includes, in addition to the foregoing electron blocking layer, an optical waveguide layer of GaN formed thereon as a part of the SCH structure and a cladding layer of AlGaN, wherein the electron blocking layer, the optical waveguide layer and the cladding layer are all doped with Mg to the concentration level of about  $5 \times 10^{19} \text{ cm}^{-3}$ . Only the uppermost contact layer of GaN is doped by Mg to the concentration level of about  $1 \times 10^{20} \text{ cm}^{-3}$ . It should be noted that the laser diode 100 of the previous embodiment also uses the Mg profile of FIG.15.

On the other hand, the Mg concentration profile of FIG.15 cannot avoid cracking in the epitaxial layers used in nitride laser diodes. Such cracks formed in the epitaxial layers provides undesirable effect of decreased efficiency of laser oscillation and increased threshold voltage. Thus, it is desirable to reduce the crack formation as much as possible.

In the experimental investigation on the laser diode 100 described previously, the inventor of the present invention has discovered that the cracks formed in the epitaxial layers of the laser diode is reduced substantially when the Mg concentration level is reduced in the p-type GaN optical waveguide layer 52 and the p-type AlGaN cladding layer 53, all located above the active layer structure 40.

Referring to FIG.16, it can be seen that the crack density observed on the surface of the cladding layer 53 is reduced sharply when the Mg concentration level in the GaN optical waveguide layer 52 and the AlGaN cladding layer 53 is reduced below the conventionally used value of  $5 \times 10^{19} \text{ cm}^{-3}$ . When the Mg concentration level is reduced below about  $4 \times 10^{19} \text{ cm}^{-3}$ , particularly below than about  $3 \times 10^{19} \text{ cm}^{-3}$ ,

1 it can be seen that the observed crack density becomes  
substantially zero. In FIG.16, it should be noted  
that the vertical axis represents the crack density  
while the horizontal axis represents the Mg  
5 concentration level.

In conformity with the crack density, the  
resistance of the laser diode 100 is reduced sharply  
when the Mg concentration level in the optical  
waveguide layer 52 and the cladding layer 53 is  
10 reduced. Thereby, a minimum resistance is reached  
when the optical waveguide layer 52 and the cladding  
layer 53 have the Mg concentration level of  $3 - 4 \times 10^{19} \text{ cm}^{-3}$  as represented in FIG.17, wherein FIG.17  
15 shows the Mg concentration level in the horizontal  
axis and the drive voltage necessary for flowing a  
drive current of 100 mA in the vertical axis. With  
further decrease in the Mg content, it can be seen  
that the resistance of the laser diode 100 starts to  
increase again, while this effect is merely attributed  
20 to the depletion of carriers in the optical waveguide  
layer 52 and in the cladding layer 53 due to the  
excessively reduced concentration level of Mg.

FIG.18 shows the doping profile of Mg for  
the laser diode 100 of FIGS.6A and 6B optimized in  
25 view of the discovery of the relationship of FIG.17.

Referring to FIG.18, the electron blocking  
layer 51 of p-type AlGaN has a composition of  
 $\text{Al}_{0.18}\text{Ga}_{0.82}\text{N}$  and is formed on the active layer  
structure 40 with a thickness of about 20 nm, wherein  
30 the electron blocking layer 51 is doped with Mg to the  
concentration level of about  $1 \times 10^{20} \text{ cm}^{-3}$ . On the  
electron blocking layer 51, the optical waveguide  
layer 52 of p-type GaN is formed with a thickness of  
about 100 nm, wherein the optical waveguide layer 52  
35 is doped with Mg to the concentration level of about  $4 \times 10^{19} \text{ cm}^{-3}$ . Further, the cladding layer 53 of p-type  
AlGaN has a composition of  $\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$  as noted

1 before wherein the cladding layer 53 is formed on the  
optical waveguide layer 52 with a thickness of about  
550 nm. The cladding layer 53 is also doped with Mg  
to the concentration level of about  $4 \times 10^{19} \text{ cm}^{-3}$ .

5 On the cladding layer 53, the contact layer  
54 of p-type GaN is formed with a thickness of about  
80 nm, wherein the contact layer 53 is doped with Mg  
to the concentration level of about  $1.5 \times 10^{20} \text{ cm}^{-3}$ .

10 According to the present invention, the  
crack density in the optical waveguide layer 52 and  
the cladding layer 53 is minimized by setting the Mg  
concentration level in the layers 52 and 53 to be  
about  $4 \times 10^{19} \text{ cm}^{-3}$  or less. Thereby, the resistance  
of the laser diode is minimized. Further, the  
15 threshold voltage of the laser diode is decreased by  
increasing the Mg concentration level in the electron  
blocking layer 51 above the foregoing value of about  $4 \times 10^{19} \text{ cm}^{-3}$ . Further, the increase of the laser diode  
resistance as a result of the excessively low impurity  
20 concentration level is also avoided.

FIG.19 shows a modification of the  
embodiment of FIG.18 in which the Mg concentration  
level in the optical waveguide layer 52 and the  
cladding layer 53 is decreased to about  $3 \times 10^{19} \text{ cm}^{-3}$   
25 in view of the relationship of FIG.17. In the case of  
FIG.19, too, the crack density in the epitaxial layers  
constituting the laser diode 100 is reduced to  
substantially zero by combining the electron blocking  
layer 51 and the contact layer 54, which are doped to  
30 a high concentration level. Thereby, the crack  
density, and hence the resistance, in the epitaxial  
layers is successfully minimized.

Further, the present invention is not  
limited to the embodiments described heretofore, but  
35 various variations and modifications may be made  
without departing from the scope of the invention.

The present application is based on Japanese

1 priority applications No.10-135425 and 10-353241 filed  
respectively on May 18, 1998 and December 11, 1998,  
the entire contents of which are hereby incorporated  
by reference.

5

10

15

20

25

30

35

1    WHAT IS CLAIMED IS

5

1. An optical semiconductor device,  
comprising:
  - a substrate of SiC having a first  
conductivity type;
  - 10      a buffer layer of AlGaN formed on said  
substrate epitaxially, said buffer layer having said  
first conductivity type and a composition represented  
by a compositional parameter x as  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ;
  - 15      a first cladding layer having said first  
conductivity type, said first cladding layer being  
formed on said buffer layer epitaxially;
  - 20      an active layer formed epitaxially on said  
first cladding layer;
  - 25      a second cladding layer having a second,  
opposite conductivity type, said second cladding layer  
being formed on said active layer epitaxially;
  - 30      a first electrode provided so as to inject  
first-type carriers having a first polarity into said  
second cladding layer; and
  - 25      a second electrode provided on said  
substrate so as to inject second-type carriers having  
a second polarity,
- 35      said buffer layer containing said first type  
carriers with a concentration level in the range from  
 $3 \times 10^{18} \text{ cm}^{-3}$  to  $1 \times 10^{20} \text{ cm}^{-3}$  and said compositional  
parameter x larger than 0 but smaller than 0.4 ( $0 < x < 0.4$ ).

35

2. An optical semiconductor device as

1 claimed in claim 1, wherein said substrate contains  
carriers of said first conductivity type with a  
concentration level in the range from  $1 \times 10^{18}$  -  $1 \times$   
 $10^{20} \text{ cm}^{-3}$ .

5

3. An optical semiconductor device as  
10 claimed in claim 1, wherein said compositional  
parameter x of said buffer layer is less than 0.09 ( $x$   
 $< 0.09$ ).

15

4. An optical semiconductor device as  
claimed in claim 1, wherein said substrate has a  
(0001)Si surface of SiC and wherein said buffer layer  
20 is formed on said (0001)Si surface in intimate contact  
with said substrate.

25

5. A method of fabricating an optical  
semiconductor device, comprising the step of: growing  
an AlGaN film having a composition of  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  ( $0 < x$   
 $< 0.4$ ) on an SiC substrate by a metal-organic vapor  
30 phase epitaxy process, under a pressure of about 90  
Torr or less.

35

6. An optical semiconductor device,  
comprising:

- 1        a substrate of SiC having a first conductivity type;
- 2        a buffer layer of AlGaN formed on said substrate epitaxially;
- 3        a first cladding layer of AlGaN having said first conductivity type, said first cladding layer being formed on said buffer layer epitaxially;
- 4        an optical waveguide layer of GaN having said first conductivity type, said optical waveguide layer being formed on said first cladding layer epitaxially;
- 5        an active layer formed epitaxially on said optical waveguide layer, said active layer containing Ga as a group III element and N as a group V element;
- 6        a second cladding layer of AlGaN having a second, opposite conductivity type, said second cladding layer being formed on said active layer epitaxially;
- 7        a first electrode provided so as to inject first-type carriers having a first polarity into said second cladding layer; and
- 8        a second electrode provided on said substrate so as to inject second-type carriers having a second polarity,
- 9        said substrate having a top surface separated from a bottom surface of said active layer by a distance of about 1.6  $\mu\text{m}$  or more.

30

- 10      7. An optical semiconductor device as claimed in claim 6, wherein said buffer layer has a composition represented by a compositional parameter x as  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ , said first cladding layer has a composition represented by a compositional parameter y as  $\text{Al}_y\text{Ga}_{1-y}\text{N}$ , and said second cladding layer has a

1 composition represented by a compositional parameter z  
as  $\text{Al}_z\text{Ga}_{1-z}\text{N}$ , said compositional parameter x having a  
value equal to or larger than 0.08 but smaller than  
0.5 ( $0.08 \leq x < 0.5$ ), said compositional parameter y  
5 having a value equal to or larger than 0.05 but equal  
to or smaller than said compositional parameter x  
( $0.05 \leq y \leq x$ ), said compositional parameter z having  
a value smaller than said compositional parameter y ( $z$   
 $< y$ ).

10

8. An optical semiconductor device,  
15 comprising:  
a substrate of SiC having a first  
conductivity type;  
a first cladding layer having a first  
conductivity type, said first cladding layer being  
20 formed on said substrate epitaxially;  
an active layer formed epitaxially on said  
first cladding layer;  
a second cladding layer having a second,  
opposite conductivity type, said second cladding layer  
25 being formed on said active layer epitaxially;  
a third cladding layer having said second  
conductivity type, said third cladding layer being  
formed on said second cladding layer epitaxially;  
a first electrode provided so as to inject  
30 first-type carriers having a first polarity into said  
second cladding layer; and  
a second electrode provided on said  
substrate so as to inject second-type carriers having  
a second polarity,  
35 said third cladding layer having a ridge  
structure,  
wherein an insulating film is interposed

1 between said second cladding layer and said third  
cladding layer, said insulating film having an opening  
in correspondence to said ridge structure, with a  
width smaller than a width of said ridge structure.

5

9. An optical semiconductor device as  
10 claimed in claim 8, wherein said contact layer covers  
a top surface and both side walls of said ridge  
structure continuously.

15

10. An optical semiconductor device as  
claimed in claim 9, wherein said first electrode  
covers a top surface and both side walls of said  
20 contact layer, corresponding respectively to said top  
surface and both side walls of said ridge structure,  
continuously.

25

11. An optical semiconductor device as  
claimed in claim 10, wherein said ridge structure is  
formed in a recess structure exposing said insulation  
30 film, and wherein said first electrode fills said  
recess structure.

35

12. An optical semiconductor device as  
claimed in claim 10 wherein said third cladding layer

1 is formed of a nitride of a group III element.

5

13. An optical semiconductor device,  
comprising:

a substrate of SiC having a first  
conductivity type;

10 a first cladding layer having a first  
conductivity type, said first cladding layer being  
formed on said substrate epitaxially;

an active layer formed epitaxially on said  
first cladding layer;

15 a second cladding layer having a second,  
opposite conductivity type, said second cladding layer  
being formed on said active layer epitaxially;

a third cladding layer having said second  
conductivity type, said third cladding layer being  
20 formed on said second cladding layer epitaxially;

a contact layer of said second conductivity  
type, said contact layer being formed on said third  
cladding layer;

25 a first electrode provided on said contact  
layer;

a second electrode provided on said  
substrate;

said third cladding layer forming a ridge  
structure having a T-shaped cross-section,

30 said third cladding layer including, at a  
bottom part thereof, a pair of cuts, such that said  
cuts penetrate from respective lateral sides of said  
ridge structure toward a center of said ridge  
structure.

1        14. A method of fabricating a semiconductor  
device, comprising the steps of:  
            forming an insulation pattern on a  
semiconductor layer such that said insulation pattern  
5        has an opening; and  
            forming, on said insulation pattern, a  
regrowth region of a nitride of Al and a group III  
element in correspondence to said opening,  
            said step of forming the regrowth region  
10      being conducted by an metal-organic vapor phase  
epitaxy process.

15        15. A method as claimed in claim 14,  
wherein said step of forming said regrowth region  
includes the step of admixing a halogen to a source  
material used in said metal-organic vapor phase  
20      epitaxy process for forming said nitride.

25        16. A method as claimed in claim 15,  
wherein said step of forming said regrowth region  
includes the step of supplying said halogen to a  
reaction chamber of a metal-organic vapor phase  
deposition apparatus, in which said metal-organic  
30      vapor phase epitaxy process occurs, separately to a  
gaseous source of nitrogen.

35        17. A method as claimed in claim 14,  
wherein said step of forming said regrowth region is

1 conducted by using a metal organic compound containing  
halogen.

5

18. An optical semiconductor device,  
comprising:
- a substrate;
  - 10 a first cladding layer of a nitride of a group III element formed epitaxially on said substrate, said first cladding layer having an n-type conductivity;
  - 15 a first optical waveguide layer of a nitride of a group III element formed epitaxially on said first cladding layer, said first optical waveguide layer having an n-type conductivity;
  - 20 an active layer of a nitride of a group III element formed epitaxially on said first optical waveguide layer;
  - 25 an electron blocking layer of a nitride of a group III element formed epitaxially on said active layer, said electron blocking layer having a p-type conductivity;
  - 30 a second optical waveguide layer of a nitride of a group III element formed epitaxially on said electron blocking layer, said second optical waveguide layer having a p-type conductivity;
  - 35 a second cladding layer of a nitride of a group III element formed epitaxially on said second optical waveguide layer, said second cladding layer having a p-type conductivity;
  - 40 a contact layer of a nitride of a group III element formed epitaxially on said second cladding layer, said contact layer having a p-type conductivity;
  - 45 a first electrode provided on said contact

1       layer; and

          a second electrode provided on said  
substrate;

5       each of said electron blocking layer, said  
second optical waveguide layer and said second  
cladding layer being doped by Mg;

10      wherein said second optical waveguide layer  
and said second cladding layer contain Mg therein with  
a concentration level lower than a concentration level  
of Mg in any of said electron blocking layer and said  
contact layer.

15

19. An optical semiconductor device as  
claimed in claim 18, wherein said second optical  
waveguide layer and said second cladding layer contain  
Mg with a concentration level not exceeding  $4 \times$   
20      $10^{19} \text{ cm}^{-3}$ .

25

20. An optical semiconductor device as  
claimed in claim 19, wherein said electron blocking  
layer and said contact layer contain Mg with a  
concentration level exceeding  $4 \times 10^{19} \text{ cm}^{-3}$ .

30

21. A semiconductor wafer, comprising:  
an SiC substrate having an n-type  
35     conductivity; and  
an AlGaN layer having an n-type conductivity  
formed on said SiC substrate with a composition

1       represented as  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ,

      wherein said AlGaN layer has a carrier  
      density in the range between  $3 \times 10^{18} - 1 \times 10^{20} \text{ cm}^{-3}$ ,  
      and

5       wherein said compositional parameter x is  
      larger than 0 but smaller than 0.4 ( $0 < x < 0.4$ ).

10

22. A semiconductor wafer as claimed in  
      claim 21, wherein said substrate contains carriers of  
      said first conductivity type with a concentration  
15      level in the range from  $1 \times 10^{18} - 1 \times 10^{20} \text{ cm}^{-3}$ .

20       23. A semiconductor wafer as claimed in  
      claim 21, wherein said compositional parameter x of  
      said buffer layer is less than 0.09 ( $x < 0.09$ ).

25

24. An optical semiconductor device as  
      claimed in claim 21, wherein said substrate has a  
      (0001)Si surface of SiC and wherein said buffer layer  
30      is formed on said (0001)Si surface in intimate contact  
      with said substrate.

35

1      ABSTRACT OF THE DISCLOSURE

An optical semiconductor device includes an  
SiC substrate having an n-type conductivity, and an  
AlGaN buffer layer having an n-type conductivity  
5      formed on the SiC substrate with a composition  
represented as  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ , wherein the AlGaN buffer  
layer has a carrier density in the range between  $3 \times$   
 $10^{18} - 1 \times 10^{20} \text{ cm}^{-3}$ , and the compositional parameter x  
is larger than 0 but smaller than 0.4 ( $0 < x < 0.4$ ).

10

15

20

25

30

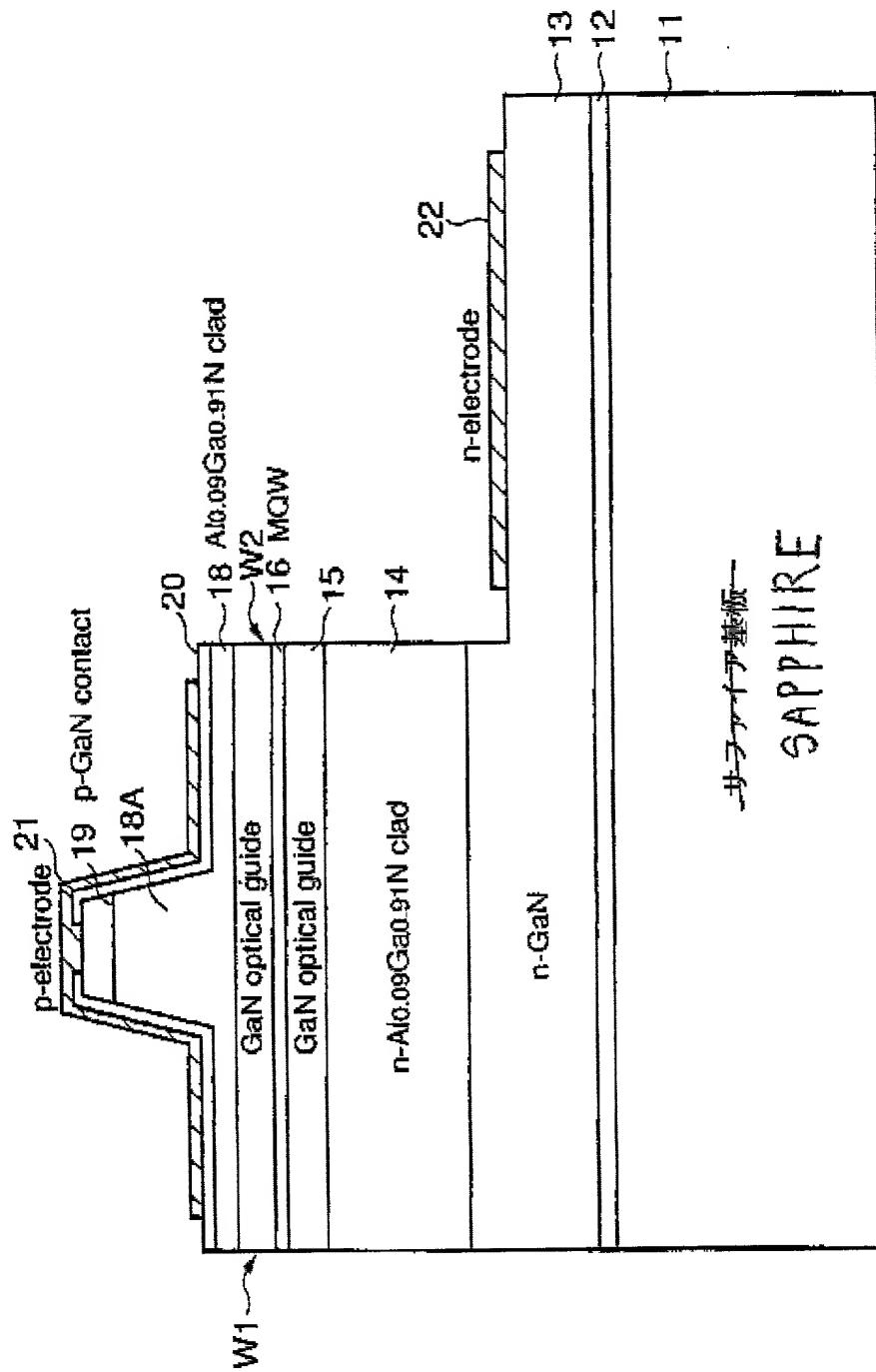
35

【書類名】 図面

【図1】

従来の青色レーザダイオードの構成を示す図

# PRIOR ART



【図2】

(A),(B)は、本発明の第1実施例の基礎となる実験で使われた試料、  
および実験結果を示す図

FIG 2A (A)

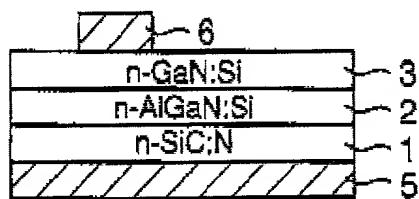
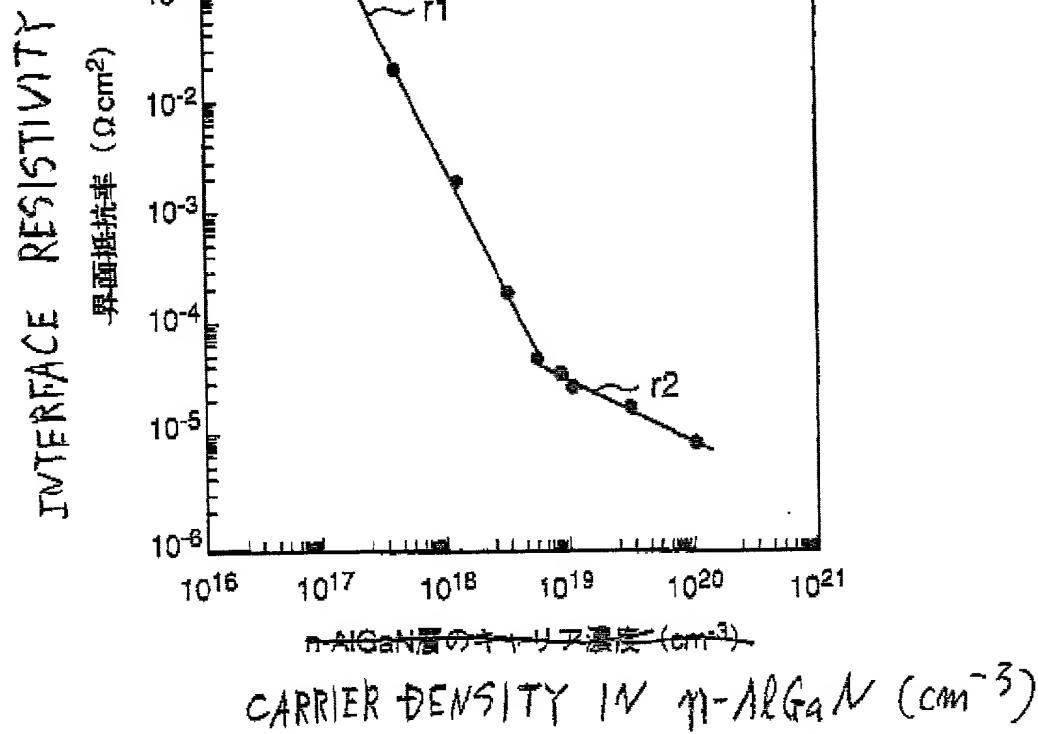


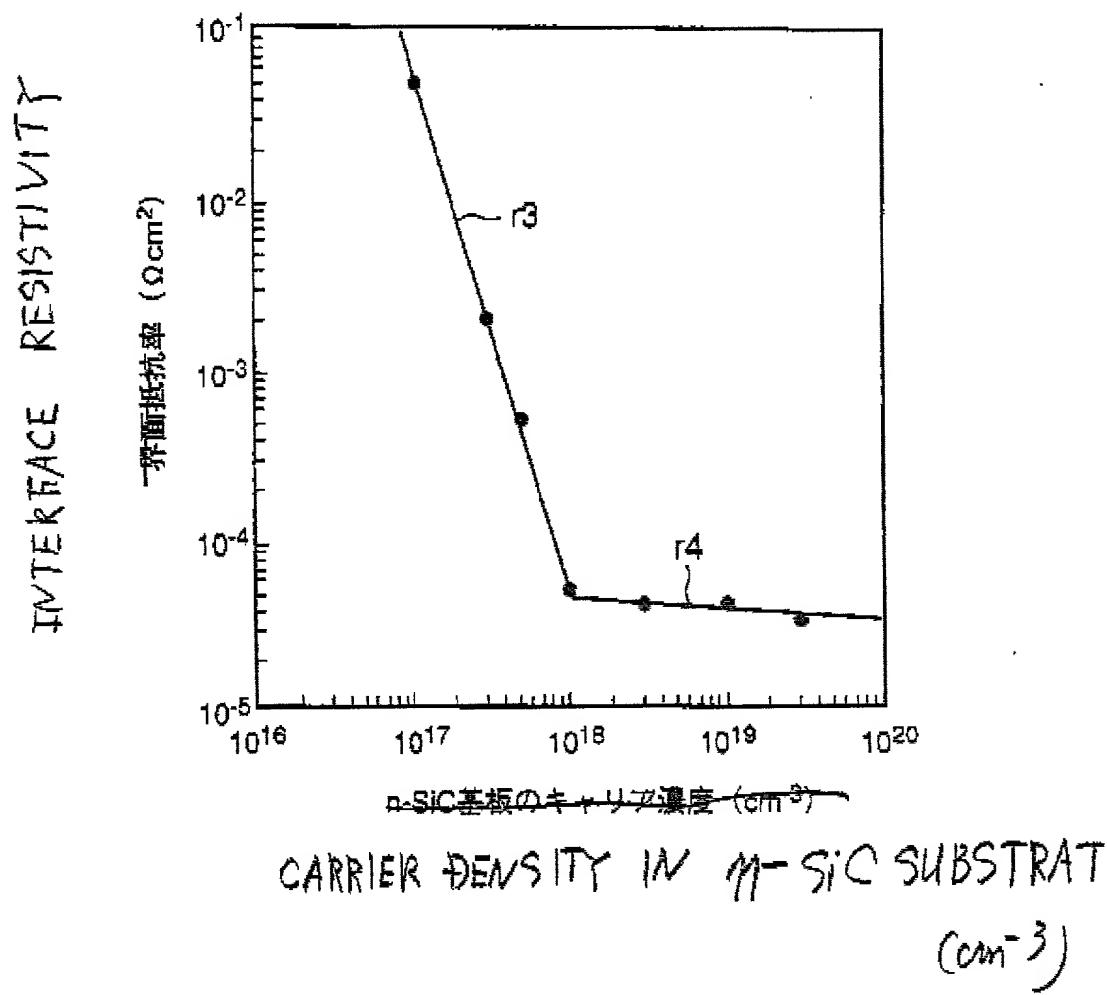
FIG 2B (B)



【図3】

FIG 3

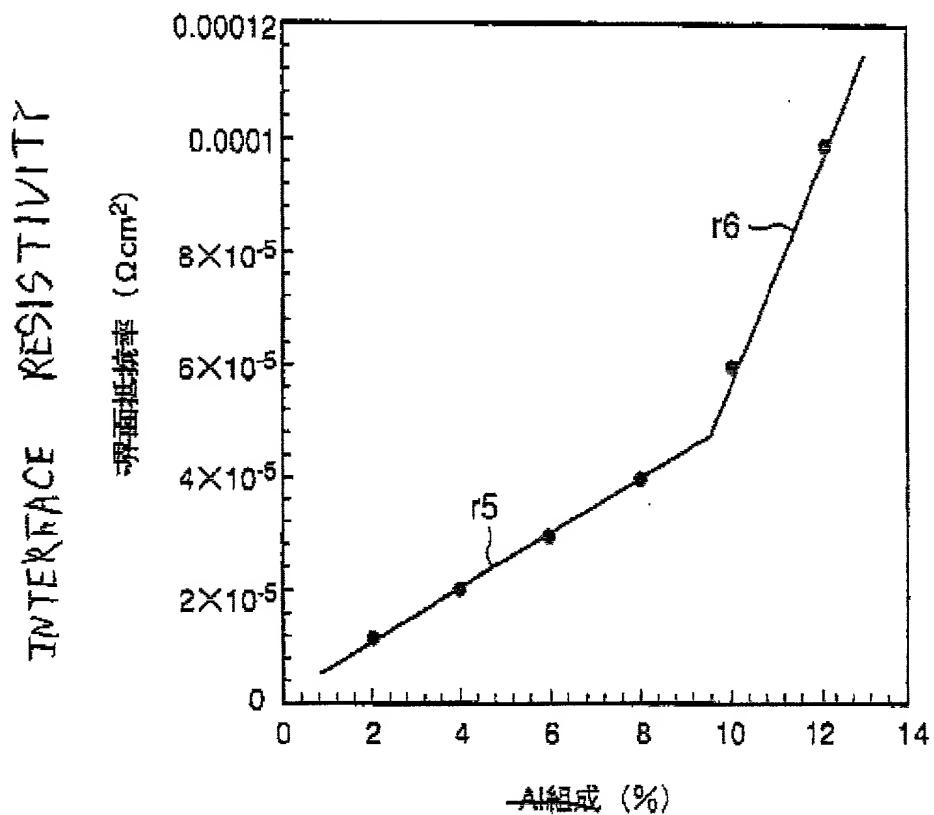
本発明第1実施例の基礎となる実験の別の結果を示す図



【図4】

FIG 4

本発明第1実施例の基礎となる実験の別の結果を示す図

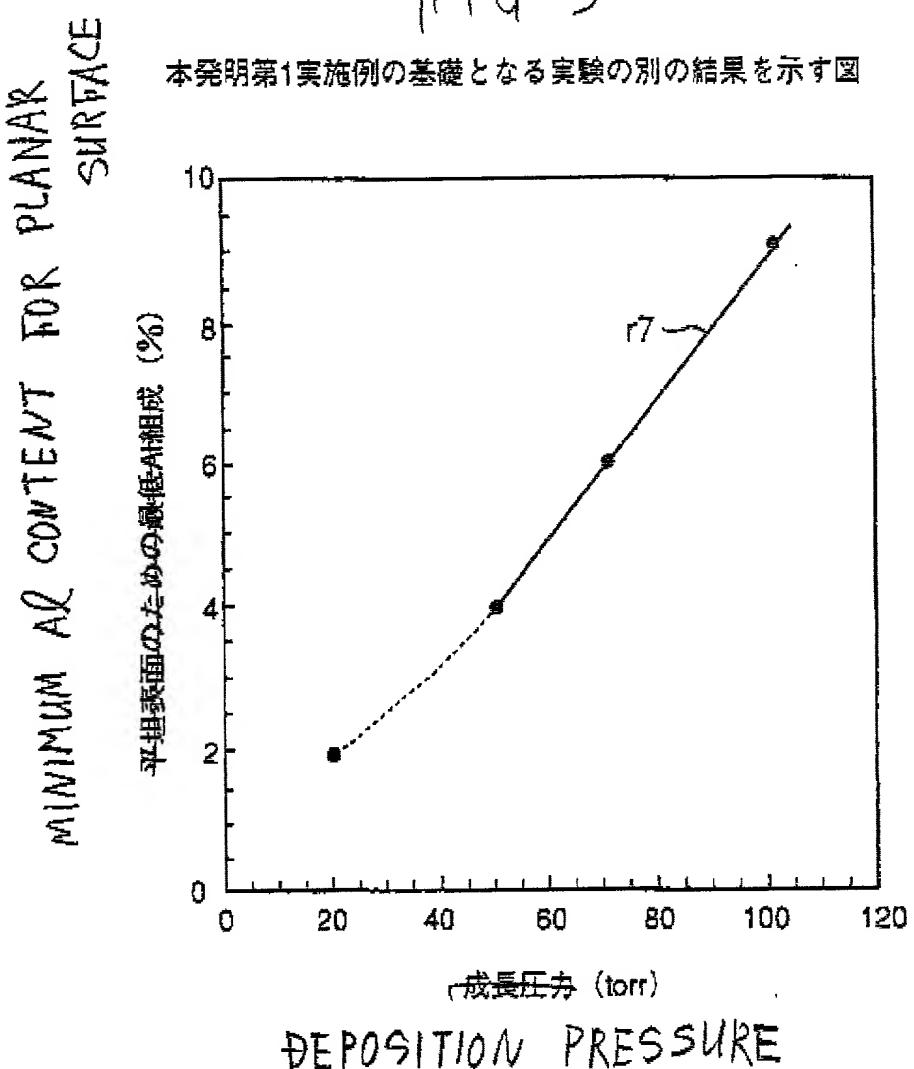


Al CONTENT

【図5】

FIG 5

本発明第1実施例の基礎となる実験の別の結果を示す図

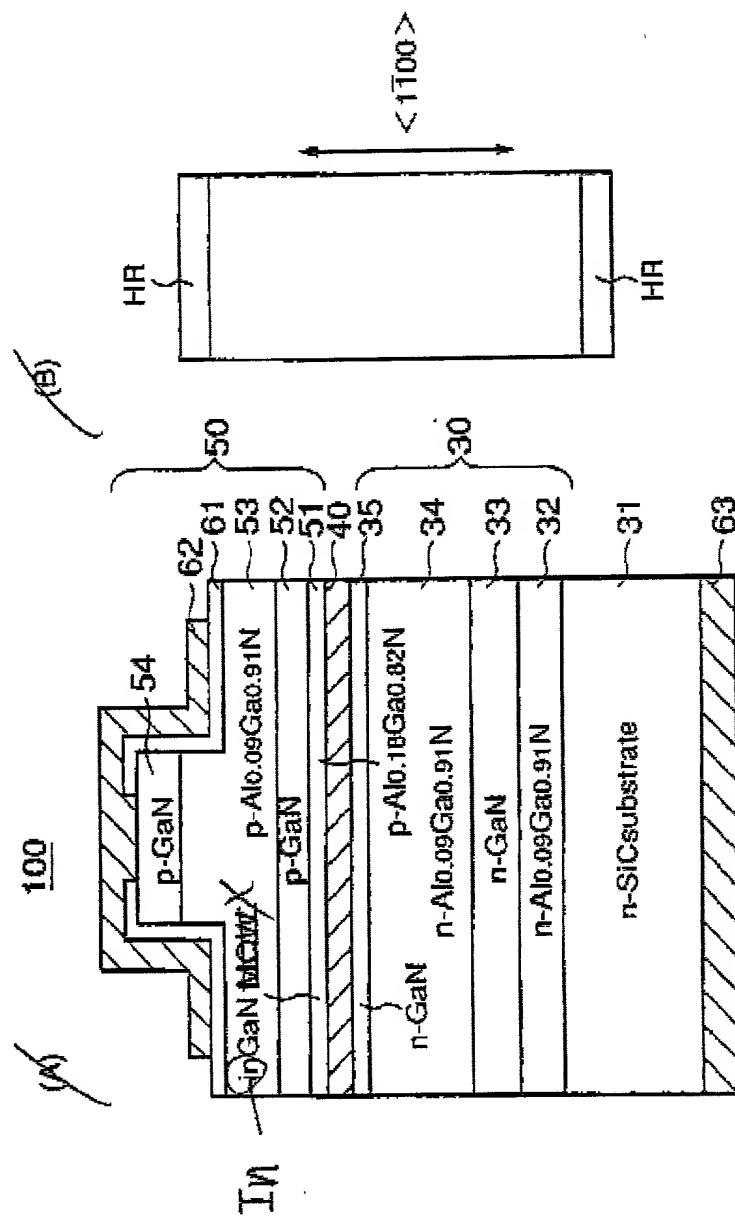


【図6】

(A),(B)は、本発明の第1実施例によるレーザダイオードの構成を示す図

T166B

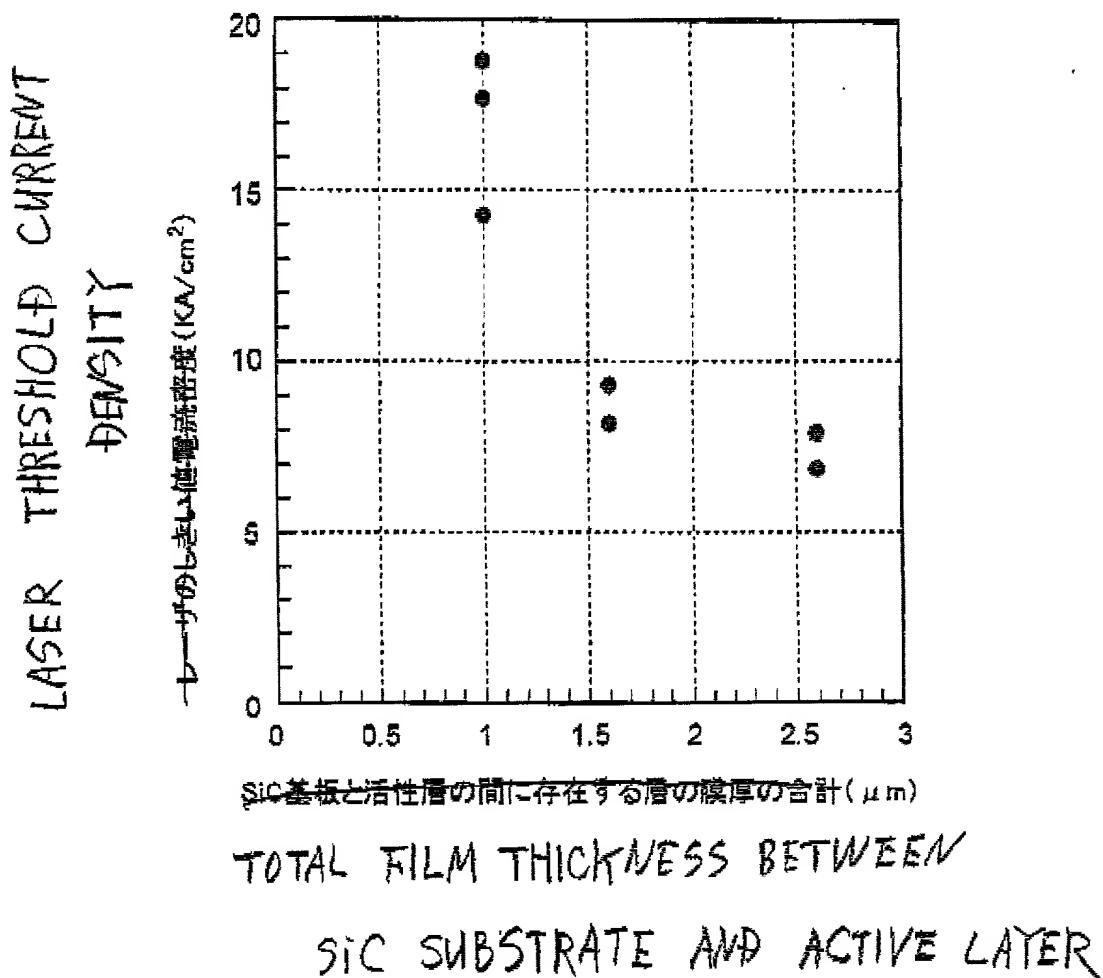
T166A



【図7】

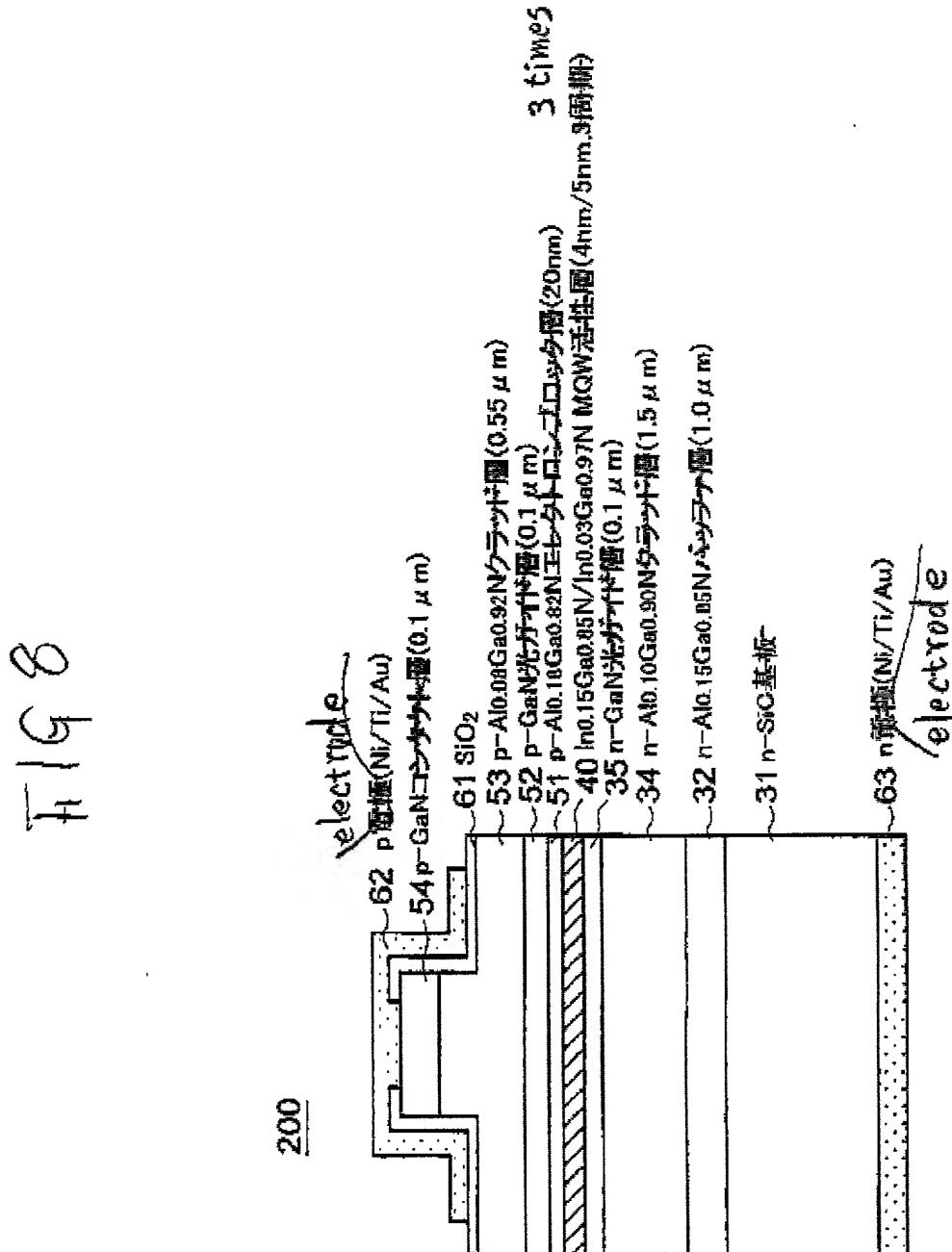
FIG 7

本発明の第2実施例の基礎となる実験の結果を示す図



【図8】

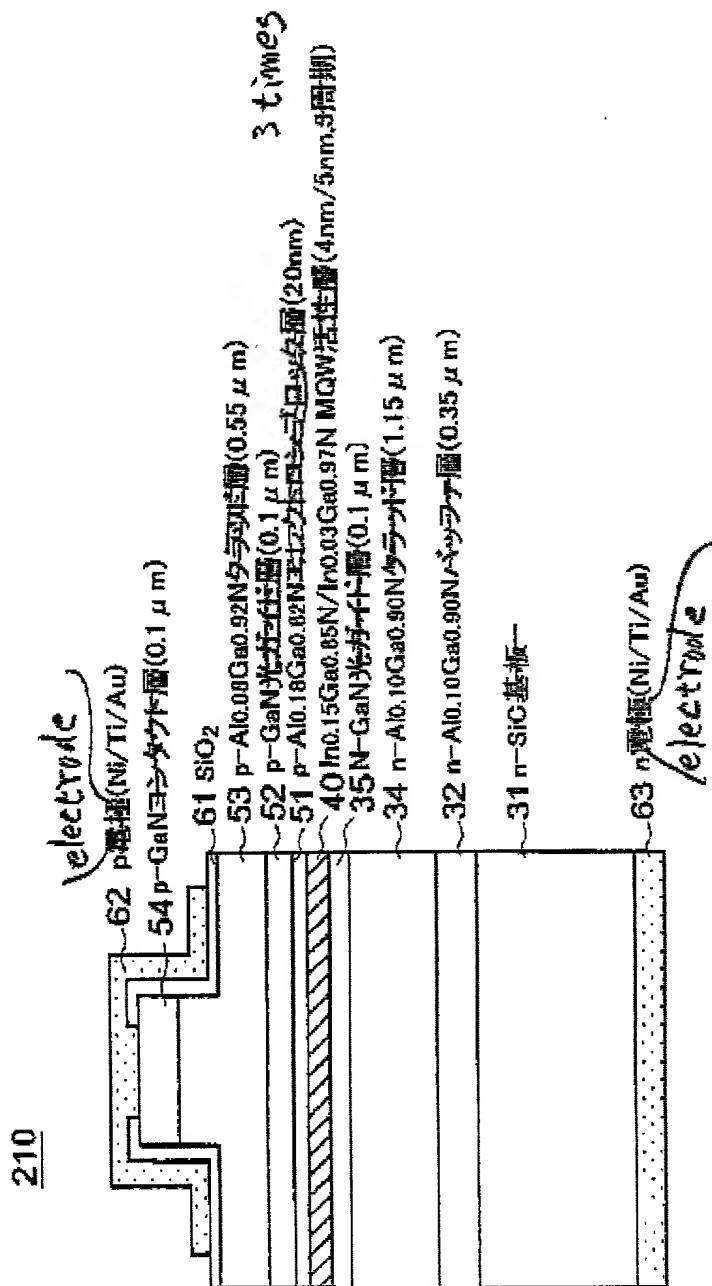
本発明の第2実施例によるレーザダイオードの構成を示す図



【図9】

図8のレーザダイオードの一変形例を示す図

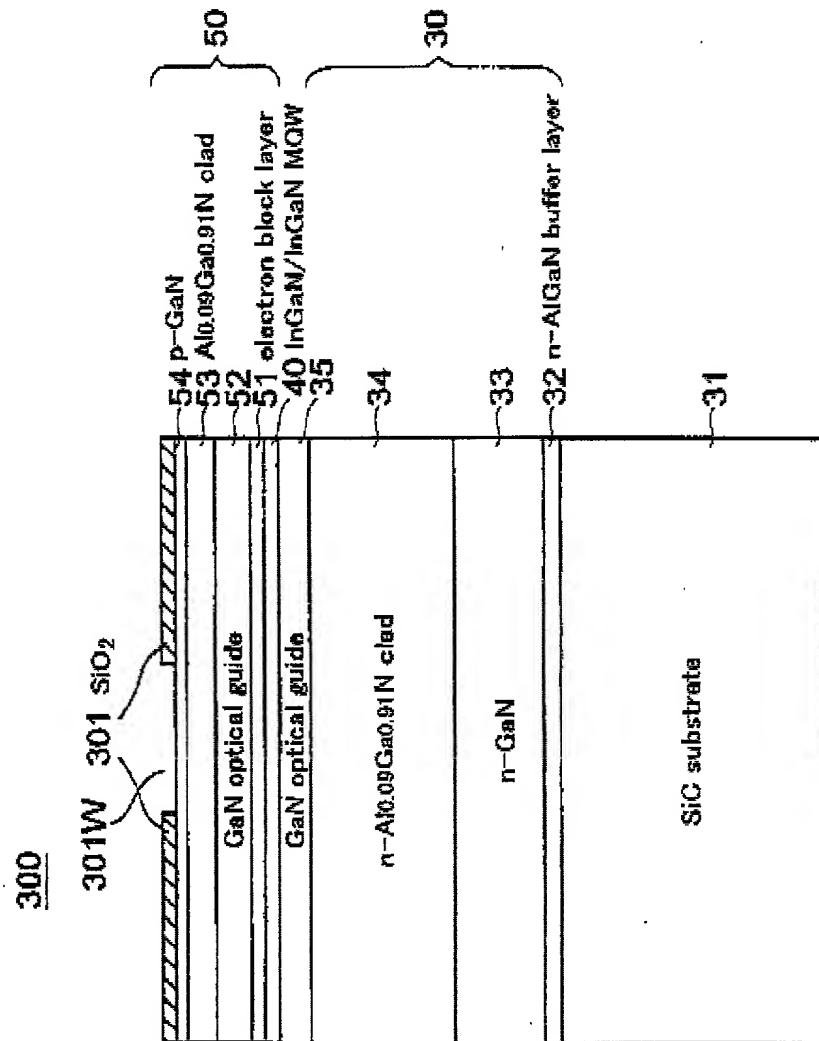
H169



【図10】

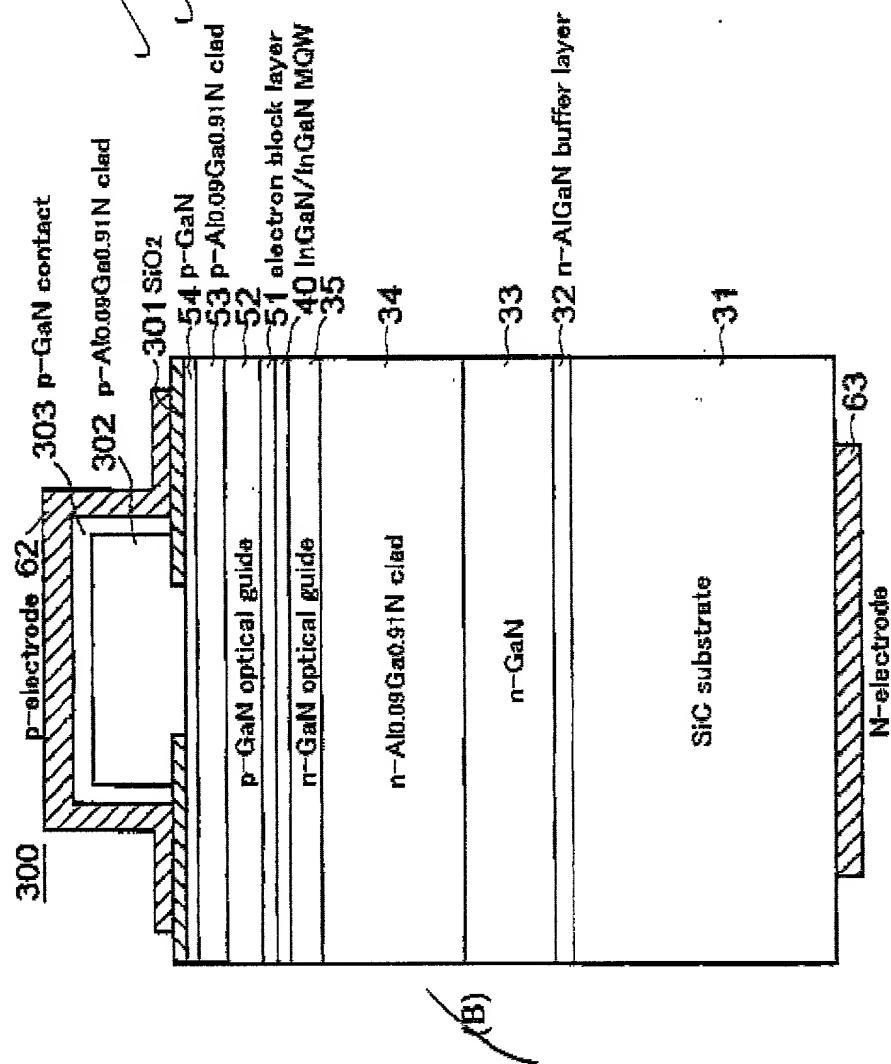
(A)は、本発明の第3実施例によるレーザダイオードの製造工  
程を示す図(その1)

FIG 10 A



【図11】

(B)は、本発明の第3実施例によるレーザダイオードの製造工  
程を示す図(その2)

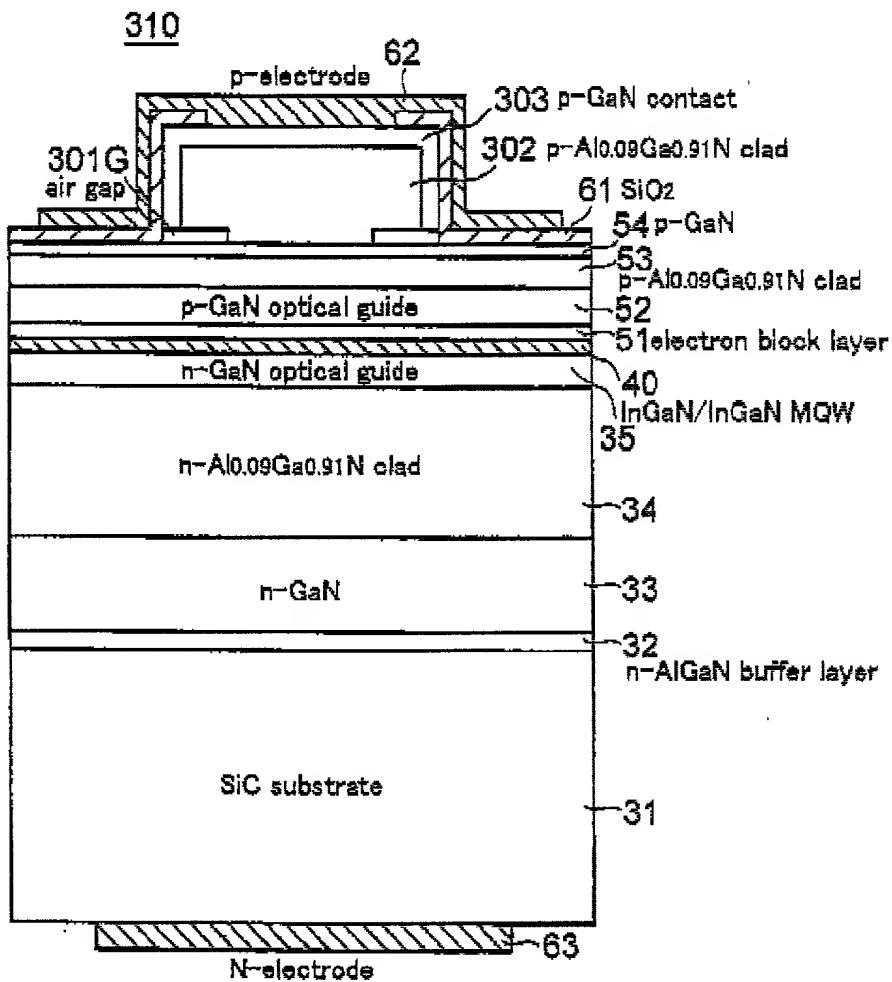


TIG103

【図12】

FIG. 11

本発明第3実施例によるレーザダイオードの一変形例を示す図

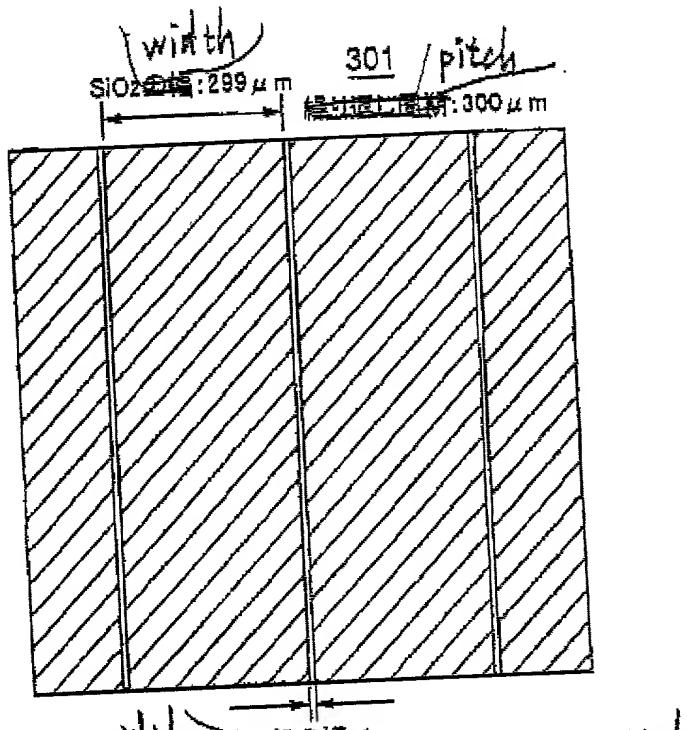


【図13】

(A),(B)は、本発明第3実施例の選択成長工程で使われるマスク、および本発明第4実施例の選択成長工程で使われるマスクを示す図

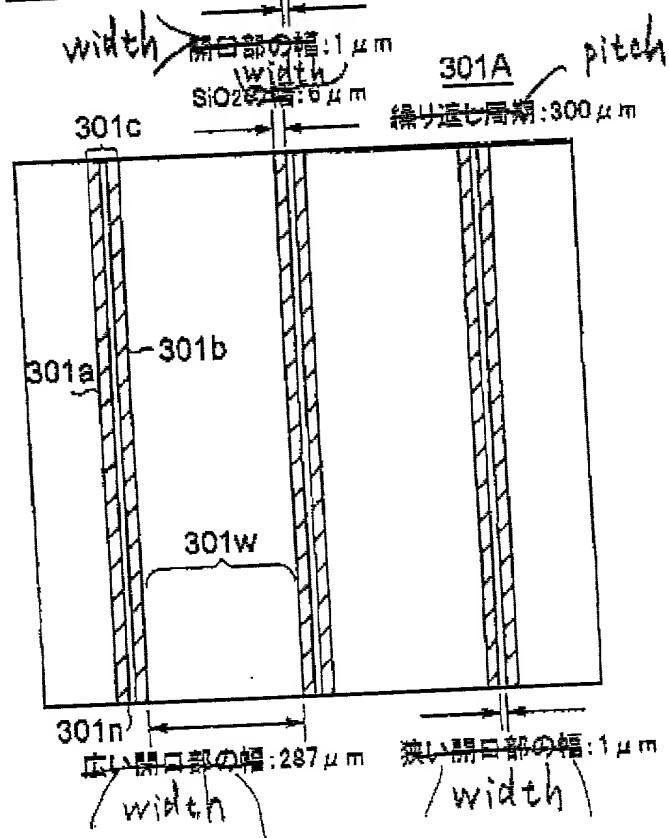
FIG|2A

(A)



FIG|2B

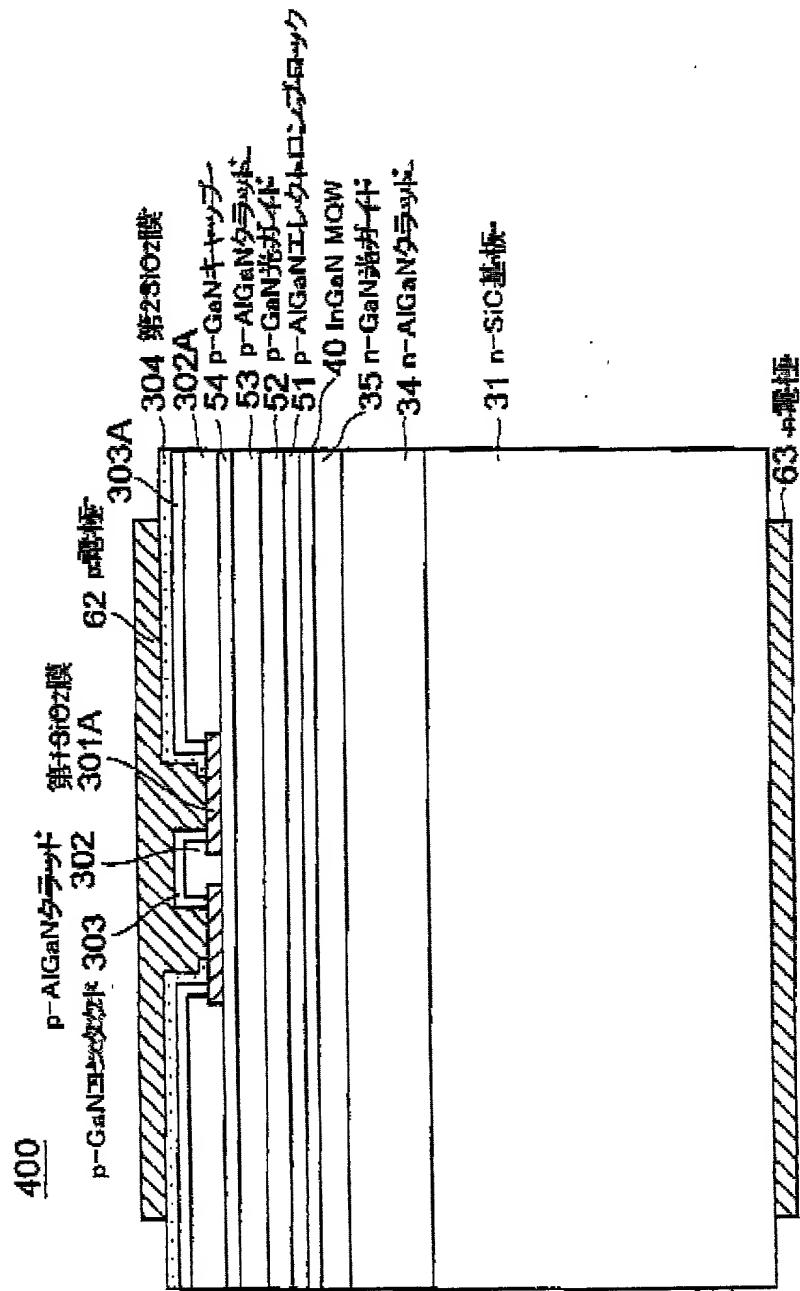
(B)



【図14】

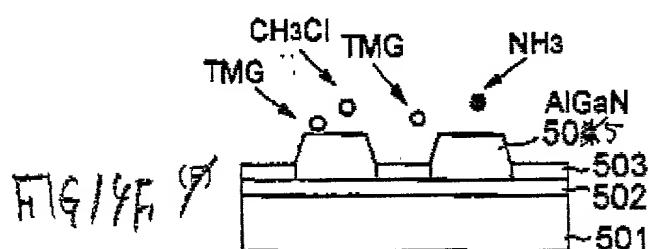
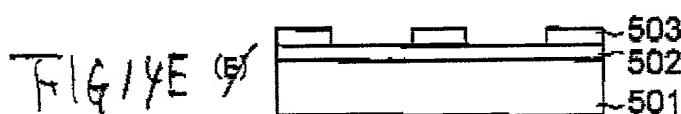
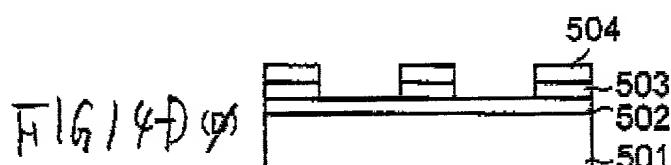
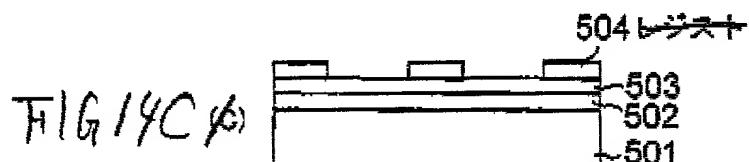
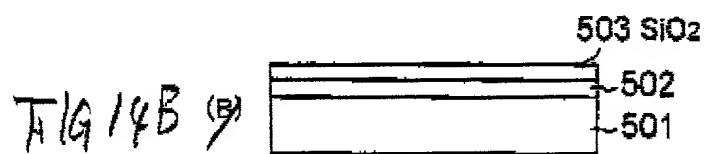
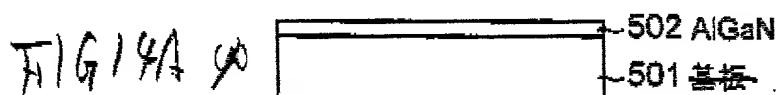
本発明の第4実施例によるレーザダイオードの構成を示す図

H | G | 3



【図15】

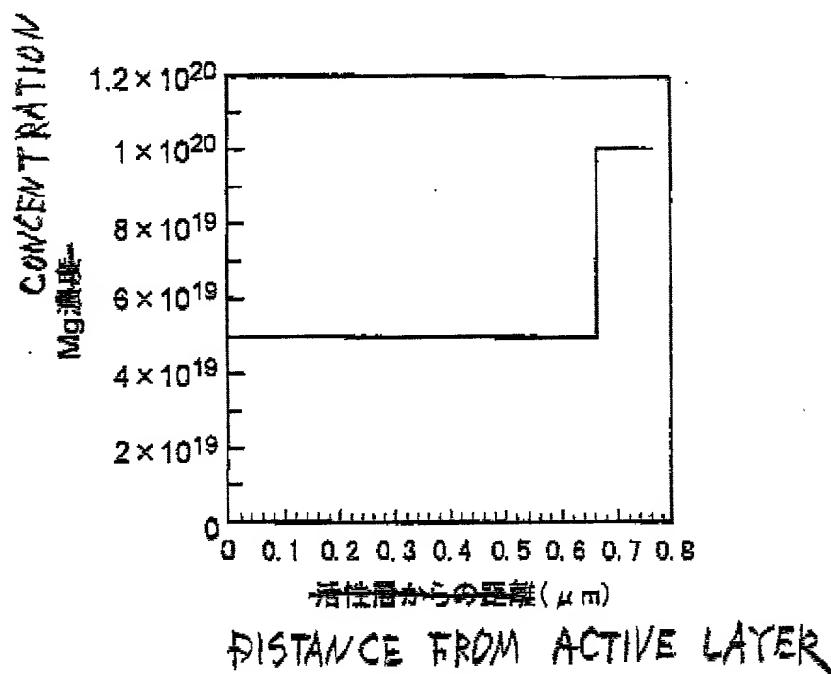
(A)~(F)は、本発明の第5実施例による選択成長工程を示す図



【図16】

TIG/5  
PRIOR ART

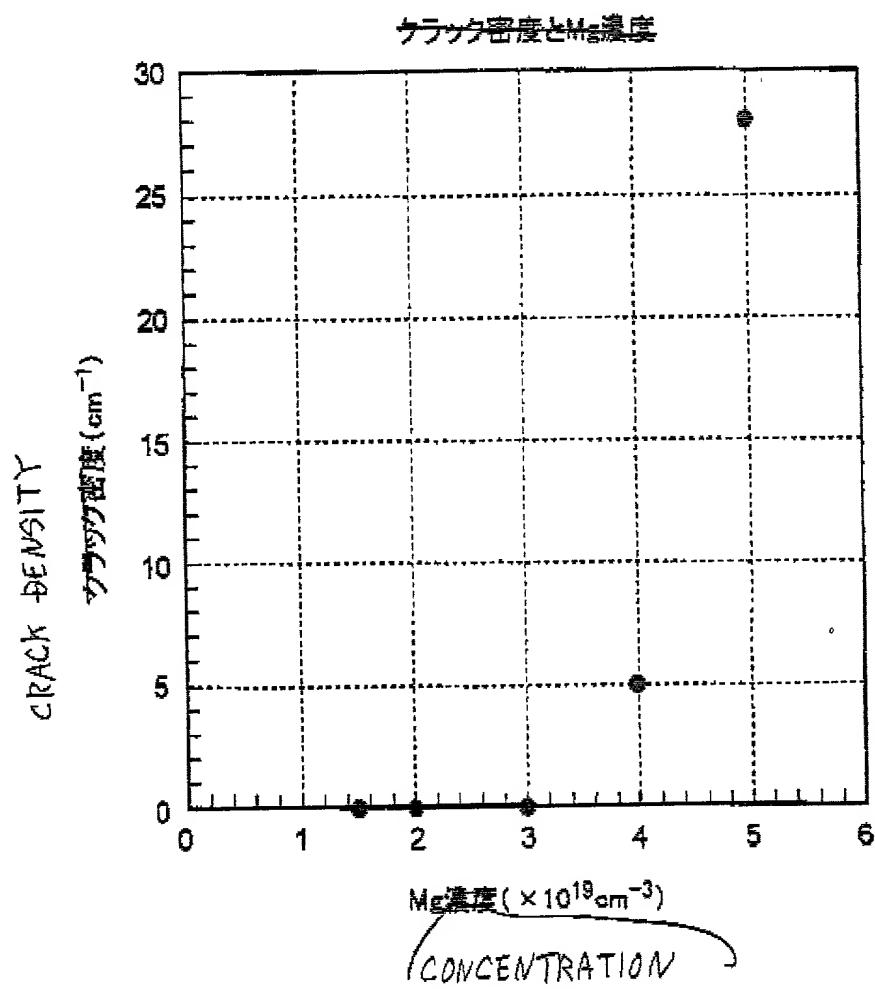
従来の青色レーザダイオードにおけるp型エピタキシャル層中の不純物分布を示す図



【図17】

FIG 16

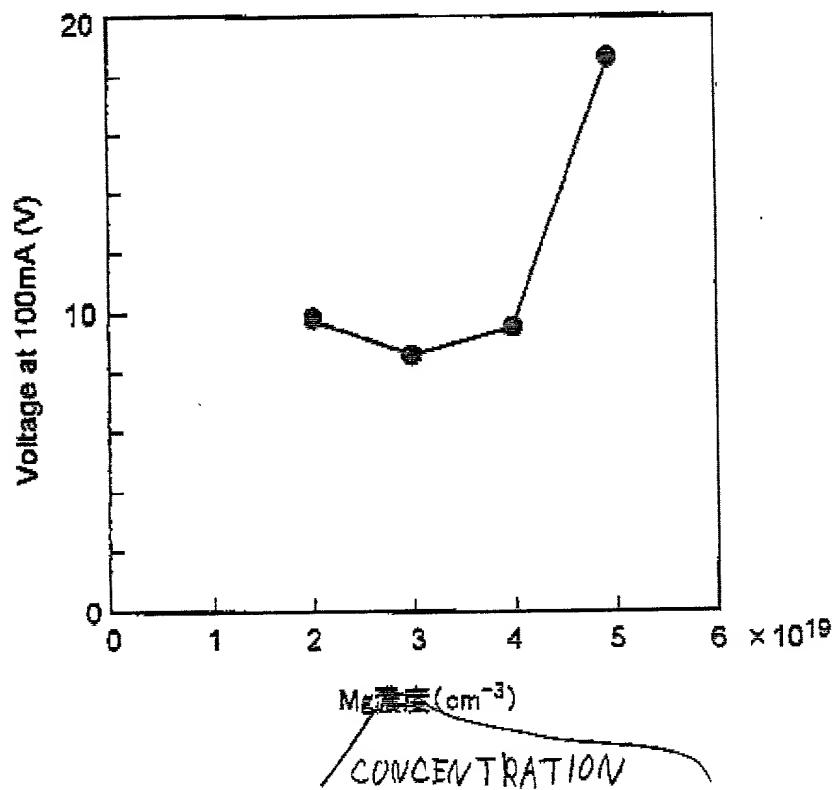
本発明の第6実施例の基礎となる実験結果を示す図



【図18】

FIG 17

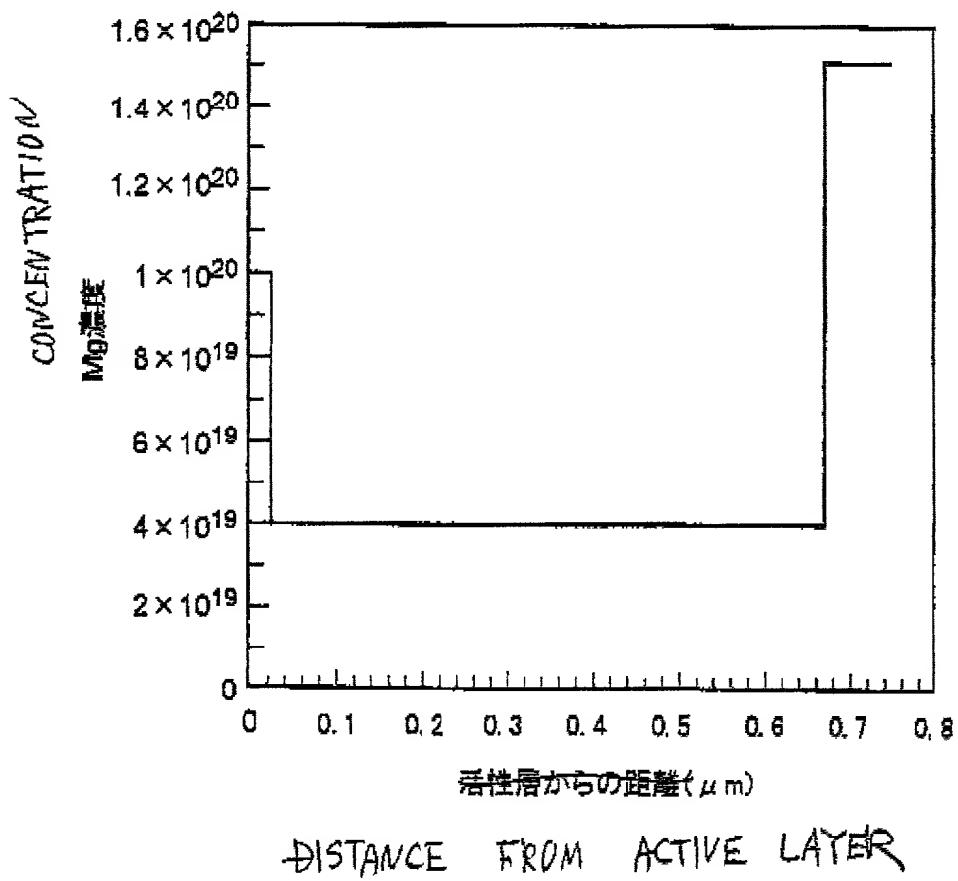
本発明第6実施例の基礎となる実験結果を示す別の図



【図19】

FIG 18

本発明の第6実施例によるレーザダイオードで使われる  
不純物分布を示す図



【図20】

FIG 9

図19の一変形例による不純物分布を示す図

